Juvenile Salmonid Use of Lateral Habitat in Middle Green River, Washington Data Report

-FINAL-

Prepared for:

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Seattle, Washington 98124-2255

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1. INTRODUCTION

The U.S. Army Corps of Engineers (Corps), Seattle District and the City of Tacoma Public Utilities (Tacoma) are currently involved in Phase I of the Howard Hanson Dam Additional Water Storage Project. The Corps completed construction of the Howard Hanson Dam on the Green River at RM 64.5 in 1962. Howard Hanson Dam (HHD) is currently operated to provide winter and spring flood control as well as enhancing summer low flow augmentation for fish resources. During spring months, Howard Hanson Dam switches from flood storage to its secondary role of conservation storage that is utilized for low flow augmentation. At this time, the amount of water released from HHD is reduced below inflow levels to allow the reservoir to refill. Refill timing and rates are based upon target instream flows that are adjusted annually in response to existing environmental conditions (e.g., snow pack, precipitation, and/or biological conditions).

The existing reservoir provides for 25,400 acre-feet (ac-ft) of summer/fall storage; 24,200 ac-ft is active storage available for enhancing instream flows below the project. In the future, the Additional Water Storage Project (AWSP) will provide up to an additional 37,000 ac-ft over existing storage by raising the existing summer conservation pool 36 ft (from 1,141 ft to 1,177 ft). The AWSP will be implemented in two phases. During Phase I, a fish passage facility will be constructed at the dam and storage will be increased by up to 25,000 ac-ft (up to 20,000 ac-ft of which will be stored for municipal water supply). Phase I also includes the option to store up to 5,000 ac-ft of water for low flow augmentation purposes to benefit downstream fishery resources. In Phase II, an additional 12,000 ac-ft of storage will be added to the Phase I conditions (9,600 ac-ft will be available for fisheries, and 2,400 ac-ft will be available for municipal and industrial water supply).

As part of the AWSP, the USACE and Tacoma are funding long-term monitoring of reach-scale juvenile salmonid habitat utilization within the 12,000 cfs floodplain of the middle Green River downstream of Howard Hanson Dam (RM 61.5 to RM 32). The purpose of long-term monitoring in the middle Green River is to demonstrate the cumulative effects of proposed conservation measures at duplicating natural riverine processes and conditions. The reach-scale juvenile salmonid monitoring program consists of conducting baseline surveys to establish a reference state from which changes resulting from programmatic and site-specific mitigation/restoration activities may be measured. Baseline juvenile salmonid monitoring will be followed by periodic surveys to identify trends in reach-scale juvenile salmonid habitat use that occur as a result of those programs.

This document describes the baseline juvenile salmonid use of lateral habitat surveys that were conducted in the middle Green River during the spring and early summer from 1998 through 2002. The baseline survey was comprised of two components: a juvenile salmonid use metric conducted from 1998-2002, and a lateral habitat availability metric conducted in 2002. The juvenile salmonid metric focused on the habitat use of Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and chum salmon (*O. keta*) as well as rainbow trout (*O. mykiss*). Funding for baseline surveys was cooperatively shared between the Corps and Tacoma to assist with adaptive management aspects of the AWSP, Tacoma's Habitat Conservation Plan, Corps Section 1135 Restoration and General Investigations programs. The objectives of the baseline juvenile salmonid use of lateral habitat surveys are:

- Establish suitable methods and site locations for monitoring juvenile salmonid emergence, habitat use, and periodicity in lateral habitat of the middle Green River;
- Determine the abundance of juvenile salmonids in the middle Green River relative to available lateral habitat types and compare the use between species and/or age classes;
- Obtain pre-construction juvenile salmonid abundance from restoration sites to provide a basis for evaluating restoration practices in the middle Green River;
- Obtain baseline habitat characteristics of the middle Green River to provide a basis for evaluating future changes in the extent and quality of lateral habitats resulting from implementation of the AWSP;
- Compare the extent and distribution of lateral habitat availability over a range of flows to facilitate an evaluation of the effect of flow level fluctuation on habitat availability, and
- Provide a management tool to help guide future flow management decisions during the juvenile salmonid outmigration period.

2. ENVIRONMENTAL SETTING

2.1 STUDY AREA

The Green River drains an area of 484 mi^2 located in the southern part of King County Washington. The mainstem Green River flows north and west for approximately 84 miles from its headwaters in the Cascade mountains. At RM 11 the Green River is joined by the Black River to form the Duwamish River before emptying into Puget Sound at Elliot Bay.

Historically, Lake Washington and Lake Sammamish, the Cedar River and the Green and White River all drained to the Duwamish River, forming one of the largest basins in Puget Sound, with a drainage area of 1,639 mi^2. Beginning in 1906, a series of natural and man-made events resulted in the separation of the Duwamish basin into three separate and smaller basins: the Lake Washington Basin (663 mi^2), which includes Lakes Washington and Sammamish and the Cedar River basin; the White River (494 mi^2); and the Green River (484 mi^2). A large flood in 1906 formed a logjam that blocked the confluence of the Green and White Rivers and shifted the majority of the White River flow south into the Puyallup River. Through channelization efforts this shift was made permanent, and the former White River channel was filled. In 1912, a public improvement district diverted the Cedar River into Lake Washington to maintain the elevation of the lake once the Ship Canal was completed, further reducing the drainage area of the Green River basin.

The Green River watershed is typically divided into three subbasins. The upper Green River extends from the headwaters to Tacoma's Headworks Diversion Dam at River Mile 61.0, which is located 3.5 miles downstream of HHD. The middle Green River includes areas draining to the mainstem between the Tacoma Headworks and the confluence with Soos Creek near Auburn at RM 33.8. The lower Green River continues to the confluence with the Black River at RM 11, which is the upstream extent of the estuary.

At its headwaters, the upper Green River generally flows through steep, mountainous terrain, restricted by narrow valley walls. Tributary streams in the headwaters are steep channels dominated by bedrock and boulders, eventually giving way to lower gradient, alluvial streams that cross the narrow upper valley before joining the main river. The mainstem river then braids and shifts across the valley floor until it enters the upstream end of the HHD reservoir at about RM 69.0. The flow regime of the upper mainstem and tributaries exhibit seasonal, bimodal peaks indicative of fall rain events and runoff of spring snowmelt.

In the middle Green River below the Headworks, the river gradient decreases until the river enters the Green River Gorge at about RM 58.5. The river drops quickly through the 13 miles of the gorge where the channel is well confined and bedrock ledges and large boulders dominate the channel. The gorge is cut through sandstone and mudstone of the Puget Group, a series of soft and erodable rock units. Below the Green River Gorge, the river decreases its overall slope to become a much gentler, lower gradient river. In this reach, the Green River travels through glacial outwash and alluvium deposited during the most recent advance of continental glaciers. The sediment carried by the river drops out below the gorge. The middle Green River has a mobile channel and currently supports at least 59 side channels (USACE 1998).

The lower Green River channel and floodplain have formed in sedimentary, volcanic, and glacial deposits. The lower basin (downstream from the Soos Creek confluence to Elliott Bay) has been almost entirely constrained between levees to provide flood protection. The levees have reduced channel migration rates by over 60% in some reaches (Perkins 1993). As a result, much of the former off-channel fish habitat has been lost. The mouth of the river at Elliott Bay and the lower portion of the river have been dredged and channelized to facilitate a Federal Navigation Channel.

Peak stream flows in the Green River occur during the winter and spring months as rainfall and snow melt runoff. Riparian wetlands bordered the channel along most of its length downstream of RM 45, and episodic floods would cause the river to overflow its banks onto the floodplain. Adjacent wetlands and valley soils retained water during precipitation events and high flows, and subsequently supplemented the river's streamflow during summer and early fall low flow periods. Side channels were also present throughout much of the river in lower gradient reaches, providing rearing habitat for juvenile salmonids. Tributaries, both small and large, provided habitat for salmonids and other fish species.

Howard Hanson Dam has affected geomorphic processes and channel morphology in the Green River basin in a number of ways. Prevention of floods greater than 12,000 cfs (formerly equivalent to a 2-year return interval event) has reduced the river's ability to form and maintain off-channel habitats. The dam also traps LWD and sediment generated in the upper Green River basin. The interruption of downstream transport of LWD is believed to have reduced the amount of LWD in the middle Green River. The trapping of sediment has reduced delivery of coarse sediment to downstream reaches, resulting in bed armoring below the dam and the gradual loss of gravel and cobble-sized material important for anadromous fish spawning. The baseline juvenile salmonid monitoring described in this document focuses on lateral river habitats between RM 32 and RM 64.5 in the middle Green River basin (Figure 1).

2.2 BIOLOGICAL RESOURCES

Over 30 species of fish inhabit the Green River, including both resident and anadromous stocks. Resident fish such as cutthroat trout (*O. clarki*), mountain whitefish (*Prosopium williamsoni*), and sculpin (*Cottus spp.*) are present throughout the Green River basin. Up to nine anadromous salmonid species historically or currently use the Green River system. These species include Chinook, coho, chum, and sockeye salmon (*O. nerka*), steelhead trout, sea-run cutthroat trout (*O. clarki clarki*), and bull trout (*Salvelinus confluentus*). Pink salmon (*O. gorbuscha*), formerly present in low numbers have been increasing rapidly over the past four years (C. Kraemer, WDFW, *pers. comm.*). Races of salmon and steelhead historically or currently present include spring, summer and fall Chinook, and winter and summer steelhead. Construction of Tacoma's Headworks eliminated adult salmon passage above the Headworks diversion dam (RM 61.0); however in recent years, a new trap and haul facility has allowed for some adult steelhead to be transported into the upper watershed.

Local salmon and steelhead harvests in the Green/Duwamish basin provide for commercial, sport, subsistence, and cultural uses to people in the greater Puget Sound Region. In particular, the Muckleshoot and Suquamish Tribes have treaty fishing rights to Green River fish, which are important to their economic and cultural sustenance. In response to the declining status of these valuable species, the U.S. Fish and Wildlife Service (USFWS) listed bull trout (64 Federal Register 58910) and National Marine Fisheries Service (NMFS) listed Puget Sound Chinook salmon as threatened (63 Federal Register 11482) requiring protection under the Endangered Species Act.

2.2.1 Chinook Salmon

Chinook salmon are the largest of all Pacific salmon and can weigh over 100 pounds; however, the average weight is closer to 20 pounds. Chinook salmon, the least abundant of the five Pacific salmon species, were historically found from the Ventura River, California to Point Hope, Alaska (Myers et al. 1998). Currently, spawning populations of Chinook exist from the San Joaquin River to the Kotzebue Sound, Alaska (Healey 1991). Green River Chinook salmon, along with 28 other Chinook stocks, have been placed into the Puget Sound Evolutionarily Significant Unit (ESU) by the National Marine Fisheries Service (NMFS) (Myers et al. 1998). The Puget Sound ESU encompasses all Chinook populations from the

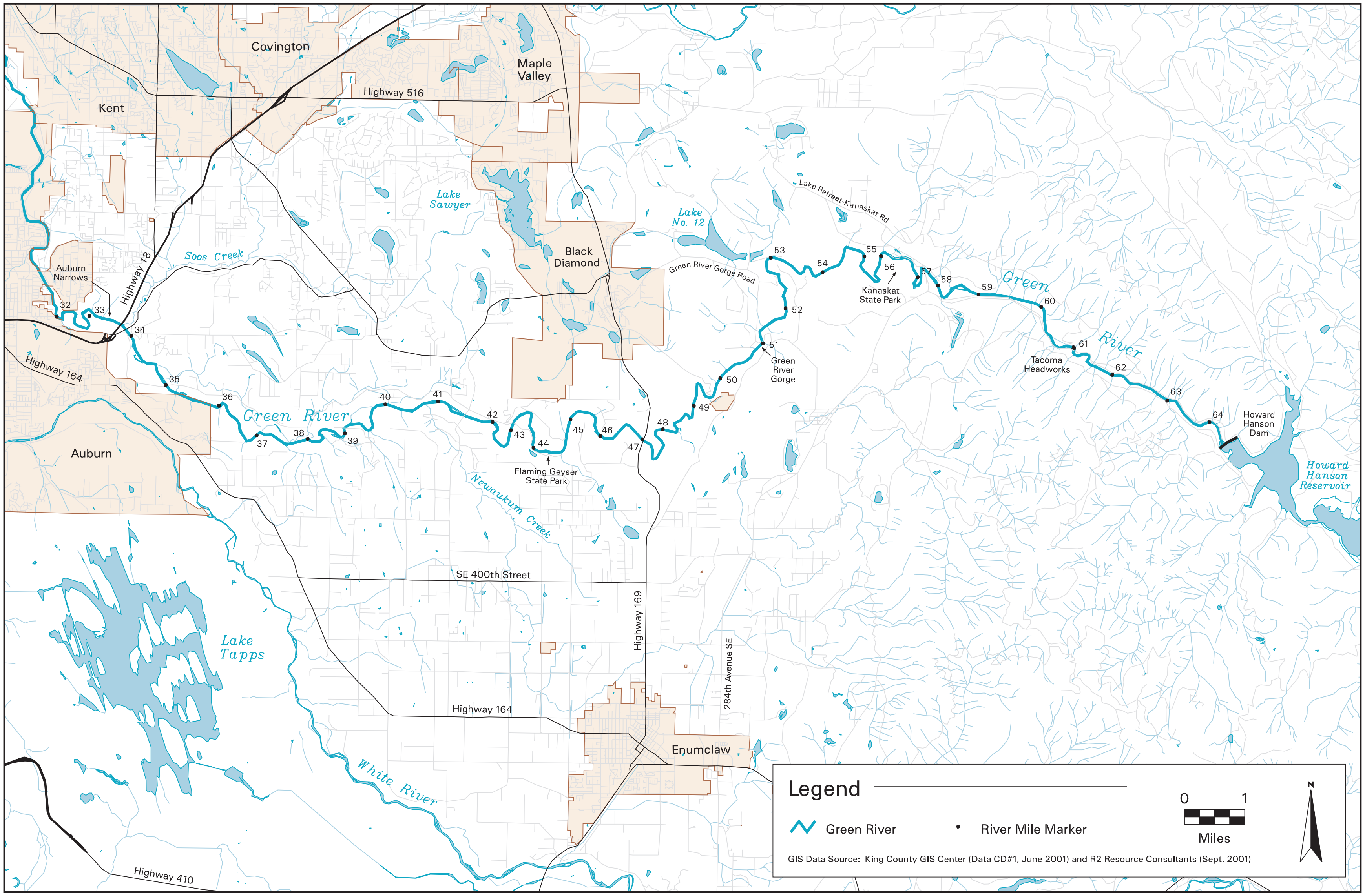

Figure 1. Location of the study area in the middle Green River, King County, Washington.

Elwha River on the Olympic Peninsula to the Nooksack River in North Puget Sound and south to the Nisqually River. The 5-year mean natural escapement (1992-1996) for the Puget Sound ESU is approximately 27,000 spawners; recent total escapement (natural and hatchery fish) has averaged 71,000 Chinook (Myers et al. 1998).

Based on timing of adult returns, most of the Chinook salmon inhabiting the Green River are of the summer/fall origin (WDFW et al. 1994). Adult summer/fall Chinook migrate upstream in the Green River from late June through November (Grette and Salo 1986). Due to their body size, the presence of deep holding water and sufficient discharge are vital to permit upstream migration. Actual adult run and spawning timing is in response to local water temperature and flow regimes (Healey 1991; Quinn 2005). Caldwell and Associates (1994) indicate that the potential for delay of upstream migration exists in August, when Green River water temperatures can exceed 21ºC (70ºF) (criteria presented in Armour 1991). Elevated water temperatures can also lead to low dissolved oxygen (DO) levels, which could also delay migration (Armour 1991).

Chinook spawning in the Green River takes place from early September through October (Grette and Salo 1986). Preferred spawning areas include the main channel from Kent (RM 24) to the Tacoma Water Supply Intake at RM 61.0 (Headworks). Spawning Chinook also utilize the lower portions of Newaukum and Big Soos creeks (King County Planning Division 1978). Larger body size also allows for use of larger spawning gravel and cobble substrates (Raleigh et al. 1986). Caldwell and Hirschey (1989) report Green River Chinook spawn over cobble with some large gravel and boulders at depths of greater than 1.0 ft to almost 3 ft occurring in water velocities ranging from about 2.0 to 3.0 feet per second (fps). Chinook eggs require 882 to 991 temperature units on average before hatching (1 temperature unit = 1 degree C above freezing for 24 hours) (Beauchamp et al. 1983). The length of incubation in the Green River varies depending on location of redds, but is generally completed by the end of February (Figure 2). Alevins remain in the gravels for 2 to 3 weeks after hatching (Wydoski and Whitney 1979).

Many variations in juvenile life history are possible within fall/summer Chinook (Healey 1991), often the result of variability in the juvenile freshwater residence period (Reimers 1973). At least four different juvenile Chinook salmon life history strategies, based upon the general designation of Reimers (1973), and local information from Nelson et al. (2004), Seiler et al. (2004a; 2004b), Warner and Fritz (1995); and Dilley and Wunderlich 1992 are present within the Green River basin:

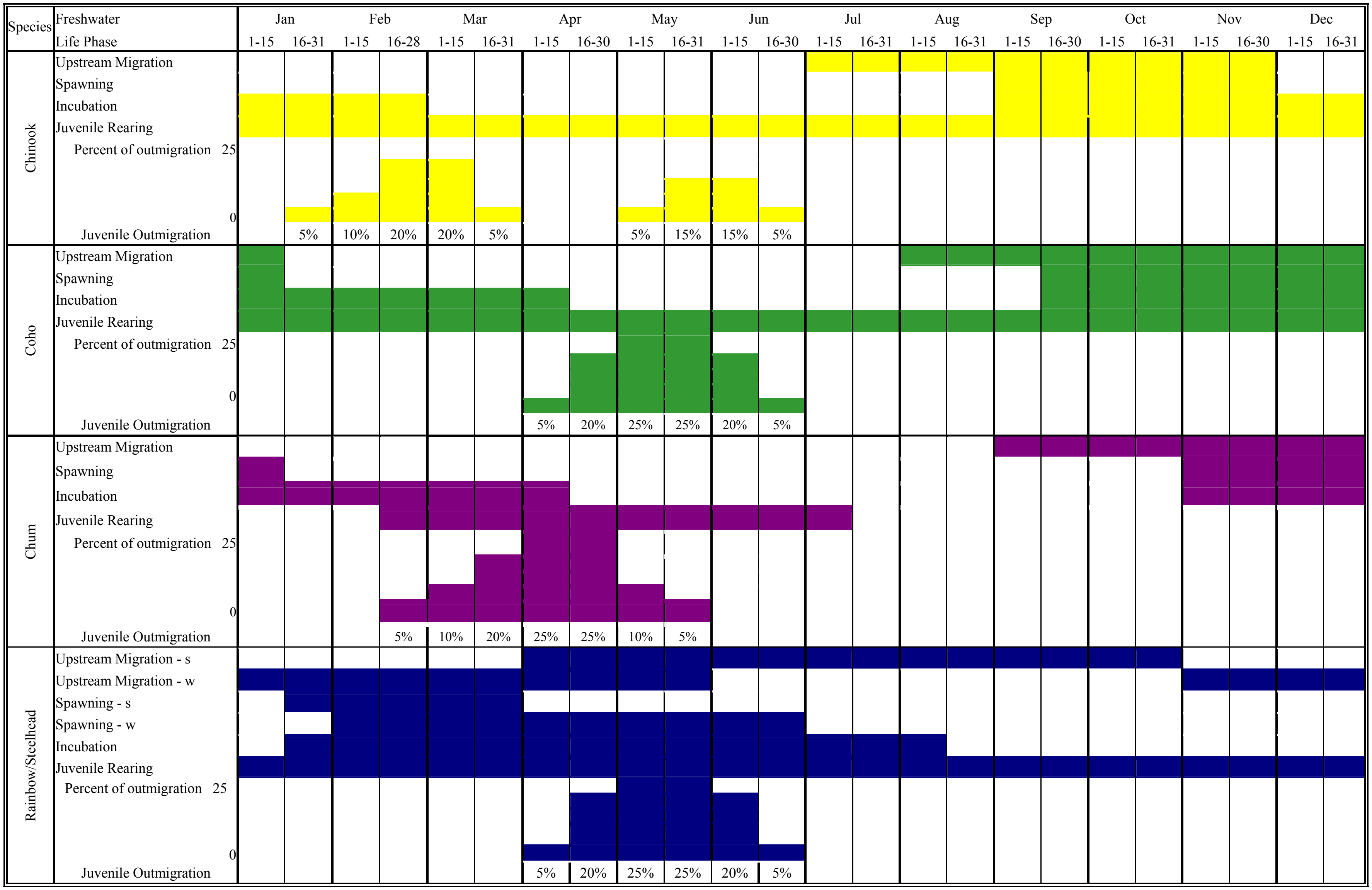

Figure 2. Temporal distribution of anadromous salmonids present in the middle Green River, King County, Washington.

- **Emergent fry** that move directly (~40 mm FL) downstream and into the lower Duwamish River/estuary within a few weeks of emergence (typically in January-March);
- **Fry/fingerlings** that rear in the Green River or tributaries until late spring/early summer (~50-70 mm FL), emigrating into the Duwamish River/estuary for an extended (3-5 month) rearing period before entering the Puget Sound;
- **Fingerlings** that rear in the main river or tributaries until early summer (~70 mm FL), then emigrate into the estuary for a short (2-3 week) rearing period before entering Puget Sound; and
- **Yearlings** that rear in tributary streams to or in the mainstem Green River until they emigrate to the Duwamish River/estuary in May during late fall high flow periods at an approximately size of 140-200 mm FL.

The proportion of Chinook present in the Green River corresponding to the above variations in freshwater rearing strategies could be dictated by genetic as well as environmental factors. Environmental cues such as streamflow reductions, food supply, changes in photo-period, water temperature, and dissolved oxygen level fluctuations are all factors that lead to the evolution and expression of particular juvenile outmigration timing (Myers et al. 1998; Quinn 2005). Specific examples of documented life history strategies in the Green River can be found in the following studies.

The U.S. Fish and Wildlife Service (USFWS) used fyke traps to gauge trends in downstream movement of subyearling Chinook planted above Howard Hanson Dam (HHD). During 1991, 979,446 subyearling Chinook were planted on 21-25 February and 960,084 were planted 6-7 March. Fyke trapping above HHD was conducted 18 April through 21 November and the peak movement of subyearling Chinook into the reservoir was observed during late May and early June (Dilley and Wunderlich 1992). During 1992 they expanded their trapping activities to extend from mid-February through the end of November. A large downstream movement into the reservoir was noted during late March and April, which was assumed to be displacement coincident with outplanting of hatchery juveniles. They observed a peak downstream movement out of the reservoir in early June, which coincided with peak adenosine triphosphate levels (Dilley and Wunderlich 1993). Based on available data, peak timing of outmigration of Chinook smolts from the upper watershed was assumed to occur between late April and early June in the upper Green River.

Dunstan (1955) used fyke nets to sample the middle Green River between 18 February and 20 May 1955 and captured newly emerged fry in late February through April. They identified the peak outmigration occurring between 7 April and 17 April. Recent juvenile salmonid surveys found that relative Chinook abundance in the middle Green River peaked in early April, while juvenile Chinook salmon (age-0) were present from 25 February through 25 June (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000). Age-1+ Chinook were also captured during juvenile salmonid surveys in the middle Green River (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000). Recently, Seiler et al. (2004a; 2004b), using a screw trap placed in the middle Green River, found catch of Chinook fry and fry/fingerling life history components peaked in March and declined to low levels by April, and virtually absent by June in 2003. Information from the 2000 outmigration period indicated that Chinook outmigration from the middle Green River peaked in late February and early March and was virtually complete by April (Seiler at al. 2002; Seiler et al. 2004a; 2004b).

Studies performed in the Duwamish Estuary indicate that peak Chinook fry abundance in the Duwamish Estuary occurs during late May (Bostick 1955; Weitkamp and Campbell 1979). Meyer et al. (1980) found the greatest abundance of juvenile Chinook during early May, even though Chinook persisted in beach and purse seine catches through July, indicating that juvenile Chinook display an extended period of residency in the Duwamish Estuary. Recent studies utilizing beach seine surveys in the lower Duwamish River indicate that Chinook salmon catches peak beginning in late April and continuing though late May (Warner and Fritz 1995; Nelson et al. 2004). Due to their plastic life history structure, juvenile Chinook are thought to migrate into and utilize estuarine habitats longer than other Pacific salmon species (Simenstad et al. 1982; Emmett et al. 1991). Extended estuarine residency period may provide for the highest growth rates that Chinook witness during their lives (SRWA 1998). Salo (1969) indicates a growth rate of approximately 1.0 inch per week in the Duwamish Estuary that could impart higher marine survival rates for the juvenile fish (Simenstad et al. 1982).

2.2.2 Coho Salmon

Coho salmon are one of the most popular and widespread sport fishes found in Pacific Northwest waters. Coho populations exist as far south as the San Lorenzo River, California, and north as Norton Sound, Alaska (Sandercock 1991). The average size of Puget Sound coho has steadily declined from 1972 (8.8 pounds) through 1993 (4.4 pounds) (Bledsoe et al. 1989). Numerous parameters, including loss of habitat and harvest practices, are thought to be associated with this decline. Coho originating in the Green River have been placed into the Puget Sound/Strait of Georgia ESU by the NMFS (Weitkamp et al. 1995). This ESU encompasses coho populations from South Puget Sound and Hood Canal to eastern Olympic Peninsula up to the Powell River Basin, British Columbia. Total average run size (from 1965 through 1993) for 17 stocks located in the Puget Sound ESU is 240,795 (Weitkamp et al. 1995).

Green River coho migrate upstream from early August through mid-January (Grette and Salo 1986) (Figure 2). As with Chinook salmon, coho require both deep holding cover for resting and sufficient instream flow (water depths of 0.6 feet) to permit upstream movement (Laufle et al. 1986). Coho spawning takes place in the Green River from late September through mid-January (Grette and Salo 1986). Coho spawn in all available tributaries and the mainstem Green River. Mainstem spawning is heaviest in the braided channel reaches near Burns Creek, in the Green River Gorge, and below the Tacoma Headworks. Major spawning tributaries include Newaukum, Big Soos, Crisp, Burns, Springbrook, and Hill creeks (Grette and Salo 1986).

Incubation periods for coho salmon last from 35 to 101 days (Laufle et al. 1986; Sandercock 1991). After hatching, larvae typically spend 3 to 4 weeks (depending on depth of burial, percentage of fine sediments, and water temperatures) absorbing the yolk sac in gravels before they emerge in early March to mid-May (McMahon 1983; Laufle et al. 1986; Sandercock 1991). Newly emerged coho (e.g., yolk sac fry) were found in the middle Green River on 25 February (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000). Coho fry continued to be present through May, with peak relative abundance occurring in mid-April (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000).

Juvenile coho salmon rear in fresh water for approximately 15 months prior to migrating downstream to the ocean, but may extend their rearing time for up to 2 years (Sandercock 1991). Newly emerged fry usually congregate in schools in pools of their natal stream. As juveniles grow, they move into more riffle habitat and aggressively defend their territory, resulting in displacement of excess juveniles downstream to less favorable habitats (Lister and Genoe 1970). Aggressive behavior may be an important factor maintaining the numbers of juveniles within the carrying capacity of the stream, and distributing juveniles more widely downstream (Chapman 1962; Sabo 1995). Once territories are established, individuals may rear in selected areas of the stream feeding on drifting benthic organisms and terrestrial insects until the following spring (Hart 1973; Cederholm and Scarlett 1981). Complex woody debris structures and side channels are important habitat elements for young-of-the-year coho salmon, particularly during the summer low flow period on the Green River (Grette and Salo 1986; Hilgert and Jeanes 1999; Jeanes and Hilgert 2000), suggesting that the abundance of juvenile coho is often determined by the combination of space, food, and water temperature (Chapman 1966; Sandercock 1991).

The peak outmigration of coho smolts in the Green River occurs between late April and early June (Figure 2). Bostick (1955) sampled outmigrating smolts in the Duwamish Estuary in 1953 and observed the peak outmigration of coho smolts in late May. Dunstan (1955) observed a peak outmigration of coho smolts during late April. Dunstan (1955) also captured newly emerged fry late February through April but characterized these early movements as being instream redistribution rather than an active migration to the Duwamish River. Seiler et al. (2002; 2004a; 2004b) found peak catches of coho smolts in late April through early May; 50% of the naturally-produced coho passed the screw trap in the middle Green River by 8 May (Seiler et al. 2002). Weitkamp and Campbell (1979) and Meyer et al. (1980) observed the greatest abundance of coho smolts in the Duwamish Estuary during late May. Meyer et al. (1980) noted that by early June coho smolts appeared to move quickly through the estuary and that few coho were present in the estuary after 4 June. Observations of peak coho smolt movement in the Duwamish Estuary may occur up to several weeks following peak movement through the lower Green River (Warner and Fritz 1995; Seiler at al. 2002; 2004a; 2004b). Outmigrating yearling coho tend to move quickly through the estuary compared to other salmonid species (Emmett et al. 1991; Warner 1995).

During 1983, coho fry were outplanted upstream from HHD and a scoop trap was operated below HHD to monitor the outmigration of coho smolts (Seiler and Neuhauser 1985). The trap was operated at regular intervals between 5 April through 18 June and observed the peak outmigration of coho smolts between early May and early June. Over 90% of smolts captured were taken during the hours of darkness. Low catches during the initial days of trapping suggested the migration began during early April, but data on the end of migration were obscured by closure of the main discharge gates at HHD on 6 June. Based on the number of coho yearlings captured during gill net sampling in the reservoir, Seiler and Neuhauser (1985) suggested downstream migration from the upper watershed continues into June.

Peak downstream movement of coho yearlings into the reservoir occurred during May and early June (Dilley and Wunderlich 1992). During 1992 they expanded their trapping activities to extend from mid-February through the end of November. Unusually warm, wet weather during February 1992 and a high early runoff coincided with downstream movement of coho yearlings into the reservoir beginning in late February and extending through May.

Even though downstream migration began in February, downstream movement into the reservoir peaked during late April and early May (Dilley and Wunderlich 1993).

2.2.3 Chum Salmon

Chum salmon, known for the large teeth and calico-patterned body color of spawning males, have the widest geographic distribution of any Pacific salmonid (Johnson et al. 1997). In North America, chum range from the Sacramento River in California, to Arctic coast streams (Salo 1991). Green River chum salmon, along with chum stocks from the Puget Sound and as far west as the Elwha River, were placed into the Puget Sound/Strait of Georgia ESU by NMFS (Johnson et al. 1997). The average chum harvest from 1988-1992 for this ESU was an estimated 1.185 million fish, equating to a total abundance of 1.5 million fish (Johnson et al. 1997).

Chum salmon migration into the Green River begins in early September and continues through December (Figure 2). Upstream migration can be very fast, with rates of 30 miles per day recorded (Salo 1991). Spawning in the Green River takes place from early November through mid-January. Preferred spawning areas are in groundwater-fed streams or at the head of riffles (Grette and Salo 1986). The major spawning areas in the Green River are the braided section of the mainstem below the Gorge and most major tributaries (Grette and Salo 1986). In general, chum salmon are reported to spawn in shallower, low-velocity streams and side channels more frequently than other salmon species (Johnson et al. 1997). Dunstan (1955) reported that most chum seemed to be produced in Burns and Newaukum creeks rather than the mainstem river. While their capture process could not differentiate between fry produced in side channels, tributaries, and mainstem habitats, spawning surveys during the 1950s identified large numbers of chum spawning in Burns Creek. Muckleshoot Indian Tribe biologists surveyed the Green River from 1996-1998 and reported significant numbers of chum spawning in side channels in the middle and lower Green River reaches (E. Warner 1998).

Like other salmonids, the length of incubation of chum eggs is influenced by water temperature, stream discharge, DO, gravel composition, and spawning time (Salo 1991). Eggs at 15°C hatch approximately 100 days before eggs incubated at 4°C. Incubation in the Green River takes place from the beginning of November to mid-April (Figure 2). Success and health of the emergent fry are also dependent on DO, gravel composition, spawner density, stream discharge, and genetic characteristics (Salo 1991; Quinn 2005).

Juvenile chum salmon have an ocean-type early life history, rearing in fresh water for only a few days to weeks before migrating downstream to salt water (Grette and Salo 1986; Johnson et al. 1997). Chum fry that migrate to sea within several days after emergence exhibit little growth, but fry that rear for longer periods may exhibit an increase in length up to 22% in less than 4 weeks (Hale et al. 1985). Hale et al. (1985) reported that chum fry grew slowly in March and April when most fry migrated to the sea, but as water temperature increased, growth of remaining fry was more rapid.

Downstream movement in the Green River occurs from mid-February through late May but varies annually. Dunstan (1955) identified an initial small surge of chum fry in late February, but believed the peak of chum fry outmigration occurred between 20 March and 3 April. Chum migration information was not accounted for in the juvenile screw trap placed in the middle Green River; however, chum fry were present in juvenile surveys conducted in the middle Green River from February through June (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000). Chum fry abundance peaked in mid-April during this study (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000).

Observations of chum fry abundance in the Duwamish Estuary also indicate movement from the Green River, but peak movement in the estuary may be several days or weeks following peak movement in the river. Meyer et al. (1980) sampled juvenile salmonids in the Duwamish Estuary from early April through early July. They noted an initial peak abundance of chum fry in late April prior to any plants of hatchery chum in the system. A second, larger peak of chum abundance occurred in mid-May, several days after the MIT released 750,000 chum fry in Crisp Creek at RM 40.0. Bostick (1955) observed peak abundance of chum in the Duwamish Estuary in early May 1953, and Weitkamp and Campbell (1979) observed peak chum abundance in late April 1978. Using beach seines to collect salmonid fry in the Duwamish Estuary during the spring months of 1994-1996, researchers observed chum fry in the estuary from February through July (E. Warner 1998). During all 3 years of study, they observed peak abundance of chum fry in the estuary in April.

Juvenile chum may remain in the brackish water habitat of the Duwamish Estuary for several days to 3 months, moving offshore as food resources decline in the summer (Meyer et al. 1980; Grette and Salo 1986). Simenstad et al. (1982) reports that eelgrass (*Zostera spp.*) habitats may be a preferred habitat of juvenile chum salmon. Juvenile chum appear to depend heavily on benthic organisms for food while residing in estuaries (Johnson et al.

1997). Like fall Chinook, their dependency on estuaries as rearing habitat may limit chum production in the Green River basin (Grette and Salo 1986).

2.2.4 Rainbow/Steelhead trout

Steelhead trout, displaying perhaps the most diverse life history pattern of all Pacific salmonids, reside in most Puget Sound streams. Their native distribution extends from the Alaska Peninsula to northern Mexico. Currently, spawning steelhead are found as far south as Malibu Creek, California (62 Federal Register 43937). Two different genetic groups (coastal and inland) of steelhead are recognized in North America (Busby et al. 1996). British Columbia, Washington, and Oregon have both coastal and inland steelhead, while Idaho has only the inland form and California steelhead stocks are all of the coastal variety (Busby et al. 1996). Within these groups, steelhead trout are further divided based on the state of sexual maturity when they enter fresh water. Stream-maturing steelhead (also called summer steelhead) enter fresh water in an immature life stage, while ocean-maturing (or winter steelhead) enter fresh water with well-developed sexual organs (Busby et al. 1996). Green River steelhead (both summer and winter stocks) have been placed into the Puget Sound ESU, along with 53 other steelhead stocks, by the NMFS (Busby et al. 1996). Total run size for the major stocks of this ESU was estimated at 45,000, and natural escapement of approximately 22,000 steelhead (Busby et al. 1996).

Steelhead that enter the Green River from May through October are considered summer steelhead, while winter steelhead move into the Green River from November through May (Grette and Salo 1986; WDFW et al. 1994). Winter steelhead are native to the Green River and spawn from mid-March through June, while summer steelhead (first introduced in 1965 from the Skamania hatchery) spawning occurs from February through March (Grette and Salo 1986; WDFW et al. 1994). Hatchery-origin winter steelhead (Chamber Creek stock) generally spawn earlier in the season than do their wild counterparts, often completing spawning by mid-March; thus, they are not thought to interbreed with wild winter steelhead (WDFW et al. 1994).

The greatest number of steelhead redds counted during WDFW surveys in the Green River between 1994 and 1996 were found in late April. Winter steelhead spawn in the Green River from approximately RM 26.0 to RM 61.0, while summer steelhead primarily spawn in the mainstream and lower tributary areas from the Headworks (RM 61.0) downstream to the upper gorge (RM 58) (King County Planning Division 1978). An anonymous Washington Department of Game Report in 1945 (as cited in USACE 1998) indicates that historically at least 90% of steelhead spawning and rearing area was located above the City of Tacoma's

Headworks at RM 61.0. Since 1982, hatchery-raised juveniles have been planted in the upper watershed; beginning in 1992, 70-133 adult steelhead have also been released upstream of the HHD (USACE 1998).

In general, steelhead differ from spawning Chinook and coho salmon by their use of faster, shallower, and higher gradient locations in mainstem or tributary streams (Everest and Chapman 1972). However, Caldwell and Hirschey (1989) observed steelhead spawning in the Green River in velocities ranging from approximately 2.0 to 4.0 fps, and depths ranging from 1.6 to 3.7 feet. Caldwell and Hirschey (1989) also report preferred spawning substrate composed of predominantly large gravel, with some small cobble. Pauley et al. (1986) found steelhead spawning in gravel ranging from 0.5 to 4.5 inches in diameter.

As with other salmonids, incubation rates for steelhead eggs vary with water temperature, with fry emergence occurring 40 to 80 days after spawning. Unlike other salmonids, steelhead require a relatively short incubation period. Dissolved oxygen levels at or near saturation with no temporary reductions in concentration below 5 parts per million are most suitable for incubation (Stolz and Schnell 1991). Everest and Chapman (1972) found age-0 steelhead residing over cobbles in water velocities of less than 0.5 fps and depths of 0.5 to 1.0 feet. Juvenile steelhead will utilize stream margins and submerged rootwads, debris, large substrate, and logs to provide shelter and cover while rearing in freshwater habitats (Bustard and Narver 1975).

Both winter and summer juvenile steelhead reside in fresh water for at least one year before migrating to the salt water (Busby et al. 1996). In the Green River, most juvenile steelhead migrate after 2 years rearing in fresh water (Meigs and Pautzke 1941). In general, juvenile downstream migration for steelhead smolts occurs from April through June, with peak migration generally occurring in mid-April (Wydoski and Whitney 1979). An early study of steelhead smolt emigration by Pautzke and Meigs (1940) found that steelhead smolts emigrated from the Green River primarily during April and May. Seiler and Neuhauser (1985) planted steelhead fry in the upper watershed during the fall of 1982 and operated a scoop trap below HHD during 1984 to monitor the outmigration of smolts. They operated the trap at regular intervals between 5 April through 18 June and observed the peak outmigration of steelhead smolts were similar to coho smolts, i.e., peaking in early May. Steelhead trout in smolt condition (physical appearance) were captured during juvenile surveys in the middle Green River during the month of May in 1998 (R2 Resource Consultants 1999). Seiler et al. (2002; 2004a; 2004b) indicated that steelhead smolts follow a similar downstream migration periodicity. Based on theses studies, the peak juvenile outmigration for the Green River during most years is assumed to be during early and mid-May (Figure 2).

Estuaries provide important nursery and schooling environments for juvenile salmonids (Shepard 1981; Simenstad et al. 1982). This transition zone allows outmigrant salmonids to physiologically adapt to the full strength saltwater conditions (SRWA 1998). However, reports that other Puget Sound steelhead smolts move quickly through estuaries, feeding in the mainstem before migrating to the ocean, indicate that they do likewise in the Green-Duwamish Estuary (Emmett et al. 1991; Warner and Fritz (1995); SRWA 1998). Meyer et al. (1980) captured more than 7,700 juvenile salmonids in surveys conducted in the Duwamish Estuary. Of these, only 50 were steelhead, representing less than 1% of the total number of salmonids captured from April through July 1980. Warner and Fritz (1995) had similar results from their lower Duwamish River beach seine surveys, furthering the idea that steelhead do not reside in estuarine habitats for extended periods of time.

3. METHODS

The study reach encompassed the middle Green River, beginning at the Headworks (RM 61.5) and continued downstream to U.S. Highway 18 (RM 33.8) (Figure 1). Selection of candidate sites was based physical data collected by Coccoli (1996) and Madsen and Hilgert (1997), and biological data collected by Hilgert and Jeanes (1999). Lateral habitat types were categorized based on physical characteristics including, but not limited to: water velocity, dominant bank substrate, bank angle, presence and type of submerged vegetation, and physical and/or observational evidence of hyporheic flow. Habitat categories were developed based on salmonid winter and spring rearing habitat preferences and utilization data gathered as part of the ongoing juvenile salmonid surveys conducted in the middle Green River since 1998 (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000). Lateral habitat types were classified using strata developed for the biological monitoring program as follows:

1) **Mainstem Habitats**: areas located within the main river channel, including:
    - ***Complex margins*** along vegetated channel banks consisting of areas with relatively low velocity (<1 fps) and cover in the form of submerged vegetation, woody debris or undercut banks;
    - ***Unvegetated margins*** along mineral channel banks or gravel bars where little or no overhead cover or bank complexity is present;
    - ***Sloughs or backwaters*** quiescent areas connected to the main flow under all flow conditions and often associated with inundated or aquatic vegetation; and
    - ***Gravel bar pools*** formed when depressions inundated during high flows become isolated from the main flow during low flow conditions.
2) **Off-Channel Habitats**: areas that separated from the mainstem Green River by a vegetated island or floodplain, including:
    - ***Backbar side channels*** located behind lateral bars or point bars formed by alluvial materials deposited by the mainstem Green River;
    - ***Abandoned side channels*** consisting of portions of the former mainstem Green River channel that presently have a direct inlet connection to the mainstem river only during moderate to high flows, and are sustained by flow through alluvial gravels (hyporheic flow) during the low flow season;

- ***Wallbase side channels*** located along the base of steep valley sideslopes and receiving a considerable proportion of their water supply from emergence of groundwater at the base of the slope; and
- ***Beaver pond complexes*** located within the floodplain and having a direct connection to the river that is passable by adult and juvenile fish on at least a seasonal basis.

3.1 JUVENILE SALMONID SURVEYS

3.1.1 Juvenile Salmonid Capture Technique

Juvenile salmonid surveys were conducted from 1998 through 2002. Juvenile salmonid surveys typically began in early February and continued through July. Juvenile salmonid monitoring sites were further separated into day and night survey strata, based on location and access. Nighttime survey sites required reasonable foot accessibility, which tended to be located within one mile of public access points (e.g., state or county parks, or fishing access sites). Daylight survey sites contained the remaining sites and were accessed from a raft launched at Whitney Bridge (218 Avenue SE) near Flaming Geyser State Park and removed at U.S. Highway 18 near Auburn, Washington.

A site reconnaissance was conducted in late January or early February to finalize site selection and prepare study sites for biological surveys. Final study site selection and preparation included the following:

- Delineating the upper and lower site boundaries;
- Quantifying available habitat area (water depth, velocity, width, and length);
- Installation of staff gages; and
- Placement of Onset Stowaway® digital temperature recorders.

Survey personnel were kept consistent throughout the study in order to maintain continuity with data collection procedures. Juvenile salmonid surveys were conducted in two-week intervals. Each two-day survey period consisted of one daytime trip followed within 24 hrs by a nighttime trip. During each survey period, the initial day survey site was started within 30 minutes of sunrise and the initial night site began within 30 minutes of sunset. Successive site start times depended largely on the amount of time that it required to complete the prior site and travel to the next site. Nighttime surveys were not conducted within four days of a full moon to avoid potential inconsistencies with lunar effects (Roper and Scarnecchia 1999). Juvenile salmonid surveys were conducted within each of the lateral habitat types in each survey year, except for beaver pond complexes which were too deep to effectively monitor using our capture techniques.

Capture techniques were standardized throughout the period of study for each site. Initial survey years (1998 and 1999) utilized various juvenile salmonid survey techniques (e.g., snorkel, fyke net, seine, minnow traps, and backpack electrofishing) (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000). Increased turbidity levels resulting from the Flaming Geyser landslide prohibited snorkeling during significant portions of the outmigration period. Capture techniques utilizing seines during the 1998 and 1999 field seasons appeared to result in undue stress on juvenile salmonids, mainly from problems associated with mud/silt substrates. While not causing direct mortalities, juvenile salmonids captured using this technique required longer periods to recover and occasionally suffered physical abrasions from the beach seine. Accordingly, this survey technique was abandoned during the 1999 field season. To maintain data collection consistency we relied solely on backpack electrofishing as the primary capture technique in the middle Green River for the majority of the 1998-2002 field seasons. The results presented in this document pertain only to those sites that were surveyed with this capture technique.

A SmithRoot, Inc. Model 15-C programmable wave output backpack electrofishing unit, using “straight DC” current was used to conduct electrofishing surveys. A block net was installed at the upstream end of each electrofishing site. Electrofishing began at the lower site boundary and continued upstream to the block net. One transect (i.e., pass) was electrofished at each survey site. Guidelines for electrofishing waters containing salmonids listed under the endangered species act (NMFS 1998) was strictly adhered to during the all field seasons. This methodology did not provide population estimates but did result in an index of abundance, while minimizing potential injury to the fish, and maintaining consistent capture methodologies throughout all survey years.

Fish were collected with a dip net (3-mm nylon mesh) and placed into a darkened recovery unit where they were anesthetized with 75 mg liter^{-1} tricaine methanesulfonate (MS 222). Each fish was identified to species, measured to the nearest mm fork length, and marked with a unique fin clip corresponding to each survey month. Captured fish, allowed to recover in fresh water for a minimum of 30 minutes, were released within the survey site that they were captured. Survey time of electrofishing transects (sec) were recorded along with individual fish data, habitat surface area (ft^2), staff gage measurements (mm), photographs, and water temperatures (°C) on field data sheets.

3.1.2 Juvenile Salmonid Data Analysis

Catch per unit effort (CPUE) data (number fish second^{-1}) was calculated for each species (coho, Chinook, and chum salmon, and rainbow and cutthroat trout) and life stage (fry and juvenile). Life stages were differentiated by length frequency analysis. Data collected from similar habitat types were combined to compare utilization of mainstem and off-channel habitat types within the middle Green River over the entire study period. Intra- and inter-site comparisons of relative abundance were conducted within the study year and between study years to classify peak emergence and emigration of juvenile salmonid species from the middle Green River. Length data was analyzed with recapture information to assign relative growth rates of each species and life stage.

Provisional stream data (river stage and discharge) was obtained from the U.S. Geological Survey and compared to available habitat information and water temperature data to analyze the effect of different flow scenarios on lateral habitats. Water temperature data were downloaded from Onset Stowaway® digital water temperature recorders and converted to daily mean, minimum, and maximum water temperatures (°C) using an in-house computer program. Relative abundance of juvenile salmonids were compared to available habitat, water temperature, and stream discharge data to determine the effects of flow regime on juvenile salmonids in the middle Green River. Stomach samples were analyzed for the presence of small fish, macroinvertebrates, or debris to determine if a change in diet composition occurs over the duration of the study. All data were entered electronically using MS Excel and cross-referenced with original field data forms for QA/QC purposes. All data analyses were conducted using MS Excel.

3.2 HABITAT SURVEYS

The location and approximate extent of lateral habitats in the middle Green River were evaluated across a range of flows in the spring and early summer of 2002. Lateral habitats are defined for this study as low velocity (<1 fps) mainstem channel margins and off-channel habitats such as backwater sloughs, beaver pond complexes and side channels. Biological monitoring has shown that these areas represent key rearing sites for juvenile salmonids in the middle Green River (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000).

Four monitoring segments were selected in relatively unconstrained reaches of the Green River. One lateral habitat monitoring segment was established within the following reaches of the middle Green River:

- Reach 1 - RM 61.5 to RM 57 - lateral habitat monitoring segment 1;
- Reach 2 - RM 45 to RM 40.7 - lateral habitat monitoring segment 2;
- Reach 3 - RM 40.7 to RM 38 - lateral habitat monitoring segment 3; and
- Reach 4 - RM 38 to RM 32 - lateral habitat monitoring segment 4.

Each monitoring segment was approximately one mile long and encompassed at least two complete pool-riffle sequences. Study segments were selected to be generally representative of conditions in unconstrained portions of each mainstem reach of interest. Channel segments that are unconstrained by natural or man-made structures on at least one bank are free to respond to changes in flow and sediment supply, and are anticipated to be the most responsive to management actions and enhancement/restoration activities implemented under the AWSP.

The inventory of lateral habitats included the mainstem Green River and all associated secondary channels, wetted side channels and other off-channel habitats that were hydraulically connected to the mainstem. Lateral habitats were mapped using a combination of ground surveys and aerial photograph interpretation. The location and physical characteristics of lateral habitats was described during ground surveys. Surveys were conducted via boat by two teams of two surveyors. One team identified and described habitats along the left bank of the river and the other team mapped and described habitats along the right bank of the river. The lateral habitat unit boundaries were recorded on field maps consisting of 1’=500 ft scale copies of 2-meter resolution black and white digital orthophotos collected in 1998. Each lateral habitat unit was assigned a unique identification code consisting of the bank designation (RB=right bank, LB=left bank) and numerical order in which units were encountered. Side channels were named according to bank (LB or RB) and the approximate river mile of the upstream most inlet or connection with the main channel. Data collected at each lateral habitat unit included the following:

1) Mainstem channel lateral habitats:
   - Habitat type (steep bank; low gradient bank; gravel bar pool; slough/backwater)
   - Bank substrate (silt/sand; gravel/cobble; boulder; bedrock; LWD or riprap);
   - Width of low velocity area (<5 ft; 5-15 ft; > 15 ft);
   - Inundated vegetation (none; grass/forb; shrub; hardwood tree; conifer tree); and
   - Abundance of woody debris (single logs, jams, or mats of small and large fragments).
2) Off-channel lateral habitats:
   - Depth of inlet hydraulic control;
   - Water temperature at inlet and outlet;
   - Water discharge (cfs) at inlet and outlet;
   - Side channel width or impoundment dimensions (beaver ponds);
   - Average water velocity;
   - Width of low velocity margins (<1 ft, 1-5 ft; 5-15 ft; >15 ft); and
   - Abundance of woody debris (single logs, jams, or mats of small and large fragments).

The length of each habitat unit parallel to the bank was measured to the nearest 1 yard using a Bushnell Compact 800 laser range finder (for units less than 300 feet long). For units greater than 300 ft, unit boundaries were marked on the orthophoto basemaps and lengths were estimated using GIS. Water velocity was measured to the nearest 0.1 fps using a Swoffer Model 2100 velocity meter and a 4-ft top-set rod. Bank substrate, vegetative cover, and wood abundance were visually estimated. The presence or absence of juvenile salmonids or other fish was noted. At least one representative photograph of each habitat type encountered was obtained from each monitoring segment, and photo points were flagged and marked to ensure replication across each flow surveyed. Unique habitat types were also documented using photographs.

Each monitoring segment was surveyed under three different flow regimes, representing high, moderate, and average flow conditions during the period when juvenile salmonids are most abundant in the middle Green River (Table 1).

Table 1. Range of half-monthly exceedance flows during the time period of 16 February through 15 June, middle Green River, Washington (calculated from USGS online data from 1964 to 1995).

USGS Gage	50% Exceedance	75% Exceedance	90% Exceedance
Green River at Auburn	1,215 - 1,638 cfs	892 - 1,070 cfs	678 - 900 cfs
Green River at Palmer	673 - 1,100 cfs	481 - 646 cfs	333 - 435 cfs

A GIS database and map were constructed of each monitoring segment for each flow regime that was surveyed. The length of lateral habitat units identified during field surveys was determined by digitizing habitat unit boundaries on orthophotos. The GIS database was used to calculate the extent of each habitat type available at each flow and to produce maps illustrating the how the location and extent of that habitat changes in each reach as a function of the flow regime.

4. RESULTS

4.1 JUVENILE SALMONID SURVEYS

Juvenile salmonid habitat utilization was monitored in 22 sites during the 1998-2002 study period (Table 2; Figure 3). In each survey year, the initial surveys were conducted in early February, continuing every other week through the final survey conducted in late June (typically 12 survey trips). Beginning in survey year 2000, juvenile salmonid surveys were continued through late July to obtain information on the emergence of juvenile steelhead trout (14 survey trips). Each habitat strata was represented by at least one survey site throughout the study period. Some survey sites were surveyed in each study year (e.g., Coho), while other sites changed or no longer were wetted and were abandoned (e.g., Rootwad Pool), while yet new sites were created and added in some study years (e.g., Porter Inlet). Eleven of the sites were surveyed during the night while 11 were surveyed during daylight hours. Mainstem margins were further divided into complex and unvegetated based upon overhead cover and bank complexity.

4.1.1 Total Catch

A total of 25,183 juvenile salmonids were captured during the study period (Table 3). Juvenile coho salmon comprised the largest total salmonid catch (9,803; 38% of total catch) as well as the largest catch of age-1+ salmonids (1,412), accounting for 14.4% of the coho catch. Age-0 Chinook salmon were the largest single age class catch (8,529), comprising more than 99% of the total Chinook catch and 33% of the total salmonid catch. Rainbow trout comprised greater than 16% of the total salmonid catch while age-0 chum salmon accounted for more than 10% of the total salmonid catch. Other salmonids captured in order of decreasing frequency of total catch were: cutthroat trout (0.1%); sockeye salmon (<0.1%); pink salmon (<0.1%); and mountain whitefish (<0.1%).

In addition to salmon, trout, and whitefish, 12 species of non-salmonids were captured during electrofishing surveys in the middle Green River. Non-salmonid species in order of decreasing capture frequency were: three-spine stickleback (*Gasterosteus aculeatus*); coastrange sculpin (*Cottus aleuticus*); mottled sculpin (*C. baidi*); largescale sucker (*Catostomus macrocheilus*); Pacific lamprey (*Lampetra tridentatus*); prickly sculpin (*C. asper*); northern pikeminnow (*Ptychocheilus oregonensis*); redside shiner (*Richardsonius balteatus*); longnose dace (*Rhinichthys cataractae*); peamouth (*Mylocheilus caurinus*); river lamprey (*L. ayresi*); and western brook lamprey (*L. richardsoni*). Combined, three-spine stickleback and coastrange sculpin accounted for more than 95% of the total non-salmonid catch.

Table 2. Name, site number, location (RM), lateral habitat strata, survey strata, and survey years of 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002.

Site No	Site	River Mile	Habitat Strata	Survey Strata	Years Surveyed
1	USGS	60.7	Complex Mainstem Margin	Night	2000-2002
2	Pipeline	59.2	Unvegetated Mainstem Margin	Night	2000-2002
3	Flaming Geyser	44.3	Unvegetated Mainstem Margin	Night	2000-2002
4	Flaming Geyser	44.2	Off-channel Backbar Ch	Night	1998-2002
5	Newaukum	40.7	Complex Mainstem Margin	Day	2001-2002
6	Upper O'Grady	40.5	Mainstem Slough	Night	1998-2002
7	Metzler Slough	40.3	Mainstem Slough	Day	2001-2002
8	Metzler Pool	40.2	Mainstem Gravel Bar Pool	Day	2000-2002
9	Lower Metzler	40.0	Off-channel Backbar Ch	Day	1998-2002
10	Middle O'Grady	40.0	Complex Mainstem Margin	Night	1999-2002
11	Lower O'Grady	40.0	Off-channel Wallbase Side Ch	Night	1998-2002
12	Blue House	39.2	Off-channel Abandoned Side Ch	Day	1998-2002
13	Visual	38.5	Unvegetated Mainstem Margin	Day	1999-2002
14	Coho	38.4	Off-channel Abandoned Side Ch	Day	1998-2002
15	Rearing Pond	36.9	Off-channel Abandoned Side Ch	Day	1999-2002
16	Big Dog	36.6	Unvegetated Mainstem Margin	Day	1999-2002
17	Rootwad Pool	36.3	Mainstem Gravel Bar Pool	Day	1998-2000
18	Seine Slough	36.0	Mainstem Slough	Day	1998,2002
19	Porter Inlet	34.4	Off-channel Abandoned Side Ch	Night	2000-2002
20	Porter Outlet	34.4	Off-channel Abandoned Side Ch	Night	2000-2002
21	Porter Levee	34.2	Off-channel Abandoned Side Ch	Night	1999-2000
22	Slaughterhouse Levee	34.2	Complex Mainstem Margin	Night	1998-2001

Table 3. Species, total number, and number captured by age class of juvenile salmonids captured (percent in parenthesis) from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002.

Species	Total Number	Age-0	Age-1+
Coho salmon	9,803 (39%)	8,391 (36%)	1,412 (62%)
Chinook salmon	8,553 (34%)	8,529 (37%)	24 (<1%)
Rainbow trout	4,206 (17%)	3,436 (15%)	770 (34%)
Chum salmon	2,744 (11%)	2,744 (12%)	0
Cutthroat trout	45 (<1%)	0	45 (2%)
Sockeye salmon	25 (<1%)	25 (<1%)	0
Pink salmon	21 (<1%)	21 (<1%)	0
Mountain Whitefish	13 (<1%)	3 (1%)	10 (<1%)
Grand Total	25,410	23,149	2,261

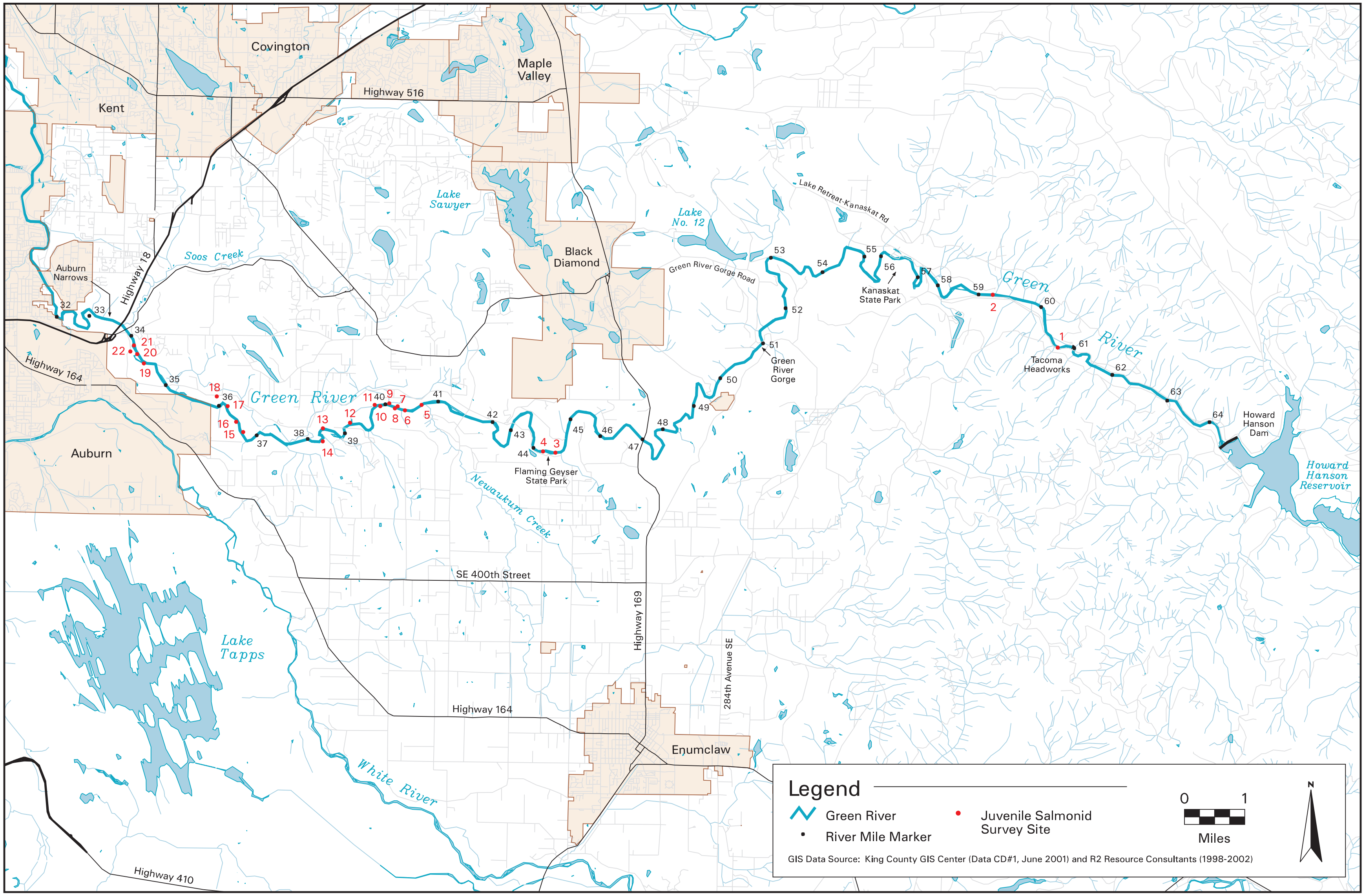

Figure 3. Location of 22 juvenile salmonid habitat utilization study sites located in the middle Green River, King County, Washington.

4.1.2 Juvenile Salmonid Habitat Utilization

Total Juvenile Salmonid

Total juvenile salmonid catch indices (i.e., all species/age classes) were significantly greater in mainstem habitats when compared to off-channel habitats over the 1998-2002 study period (Mann Whitney Rank Sum Test; T = 288, P = 0.0225). Over the study period, the most pronounced difference between mainstem and off-channel habitats was in 1998, when mainstem habitats average 0.095 juvenile salmonids·sec^{-1} (std. dev. = 0.050) and off-channel habitats 0.011 (std. dev. = 0.004). Juvenile salmonid catch indices were highest in mainstem gravel bar pools (mean = 0.053; std. dev. = 0.005) followed by mainstem sloughs (mean = 0.039; std. dev. = 0.002); mainstem margins (mean = 0.031; std. dev. = 0.003); off-channel wallbase channels (mean = 0.028; std. dev. = 0.001); off-channel backbar channels (mean = 0.0148; std. dev. = 0.008); and off-channel abandoned side channels (mean = 0.0147; std. dev. = 0.008) (Figure 4). However, except for the juvenile salmonid mainstem gravel bar pool vs. off-channel abandoned side channel habitat strata pairing (Student-Newman-Keuls Test; Q = 5.06, P = 0.0456), mean total juvenile salmonid catch indices from habitat strata were not significantly different over the entire study period or within individual study years. No significant difference occurred in average total juvenile salmonid catch indices across survey strata (day vs. night) throughout the study period (Mann Whitney Rank Sum Test; T = 164.0, P = 0.2101) or within study years.

There was a significant difference between age-0 juvenile salmonid catch indices in mainstem habitats when compared to off-channel habitats over the 1998-2002 study period (Mann Whitney Rank Sum Test; T = 211, P < 0.0001) (Figure 5). Age-0 juvenile salmonid catch indices were significantly different between habitat strata within individual years (Table 4). No significant differences occurred in average total juvenile salmonid catch indices across survey strata (day vs. night) throughout the study period (Mann Whitney Rank Sum Test; T = 158.0, P = 0.0913) or within study years.

Overall, there was not significant difference between age-1+ juvenile salmonid catch indices in mainstem habitats when compared to off-channel habitats over the 1998-2002 study period (Mann Whitney Rank Sum Test; T = 158.5, P = 0.6644) (Figure 6). However, within years, age-1+ juvenile salmonid catch indices were significantly different between habitat strata, most notably pairings involving wallbase side channels (Table 5). No significant differences occurred in average total juvenile salmonid catch indices across survey strata (day vs. night) throughout the study period (Mann Whitney Rank Sum Test; T = 141.0, P = 0.1045) or within study years.

Table 4. Pairwise multiple comparison test (+ = P<0.05; - = P>0.05) of age-0 juvenile salmonid capture indices by habitat strata from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002 (mgbp = gravel bar pool; mm = margin; ms = slough; asc = abandoned side channel; bbsc = backbar side channel; wbsc = wallbase side channel).

Habitat Strata Comparison	1998	1999	2000	2001	2002
mgbp vs. bbsc	+	+	+	+	+
mgbp vs. wbsc	+	+	+	+	+
mgbp vs. asc	+	-	-	-	+
mgbp vs. ms	-	-	-	-	-
mgbp vs. mm	-	-	-	-	-
mm vs. bbsc	+	+	+	+	+
mm vs. wbsc	+	+	+	+	+
mm vs. asc	+	+	+	+	+
mm vs. ms	-	-	-	-	-
ms vs. bbsc	+	+	+	+	+
ms vs. wbsc	+	+	+	+	+
ms vs. asc	+	-	-	-	+
asc vs. bbsc	+	+	+	+	+
asc vs. wbsc	-	-	-	-	-
wbsc vs. bbsc	-	-	-	-	-

Table 5. Pairwise multiple comparison test (+ = P<0.05; - = P>0.05) of age-0 juvenile salmonid capture indices by habitat strata from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002 (mgbp = gravel bar pool; mm = margin; ms = slough; asc = abandoned side channel; bbsc = backbar side channel; wbsc = wallbase side channel).

Habitat Strata Comparison	1998	1999	2000	2001	2002
mgbp vs. bbsc	-	-	-	+	+
mgbp vs. wbsc	-	+	+	+	+
mgbp vs. asc	+	-	-	-	+
mgbp vs. ms	-	-	-	-	-
mgbp vs. mm	-	-	-	-	-
mm vs. bbsc	-	-	-	-	-
mm vs. wbsc	+	+	+	+	+
mm vs. asc	-	-	-	-	-
mm vs. ms	-	-	-	-	-
ms vs. bbsc	-	-	-	+	+
ms vs. wbsc	-	+	+	+	+
ms vs. asc	-	-	-	-	-
asc vs. bbsc	-	-	-	-	-
asc vs. wbsc	-	-	-	-	-
wbsc vs. bbsc	-	-	-	-	-

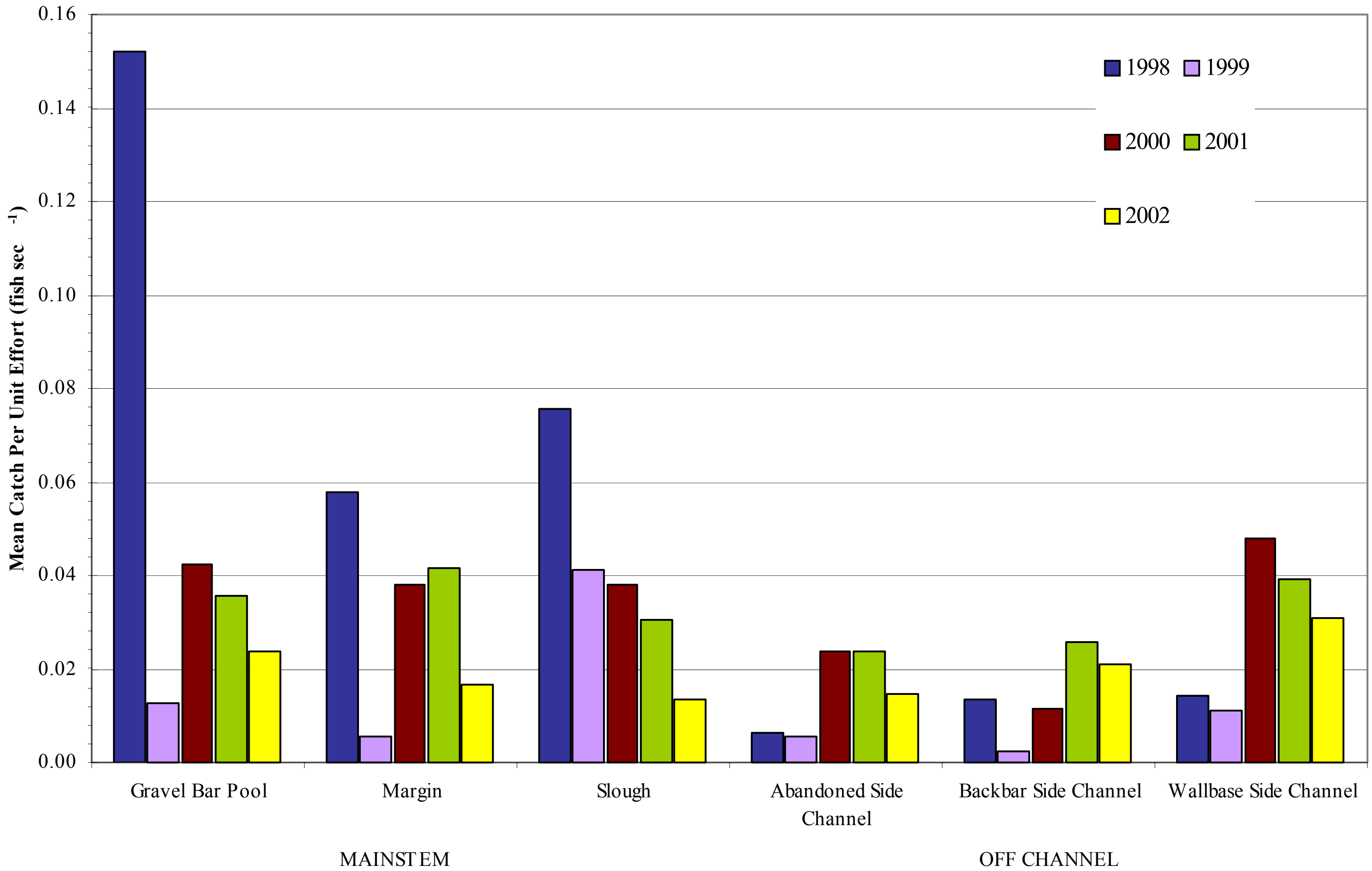

Figure 4. Average total juvenile salmonid catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

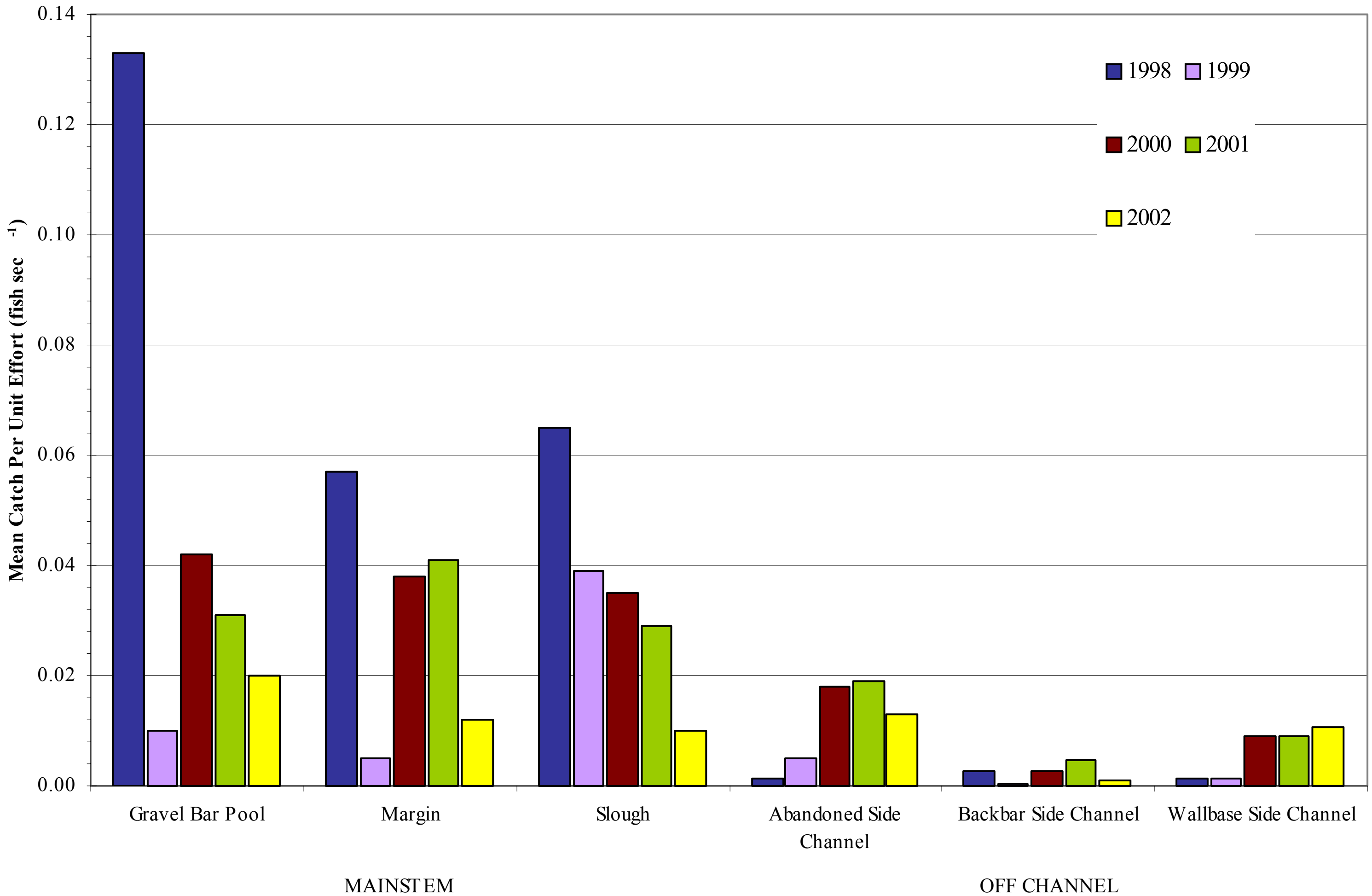

Figure 5. Average age-0 juvenile salmonid catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

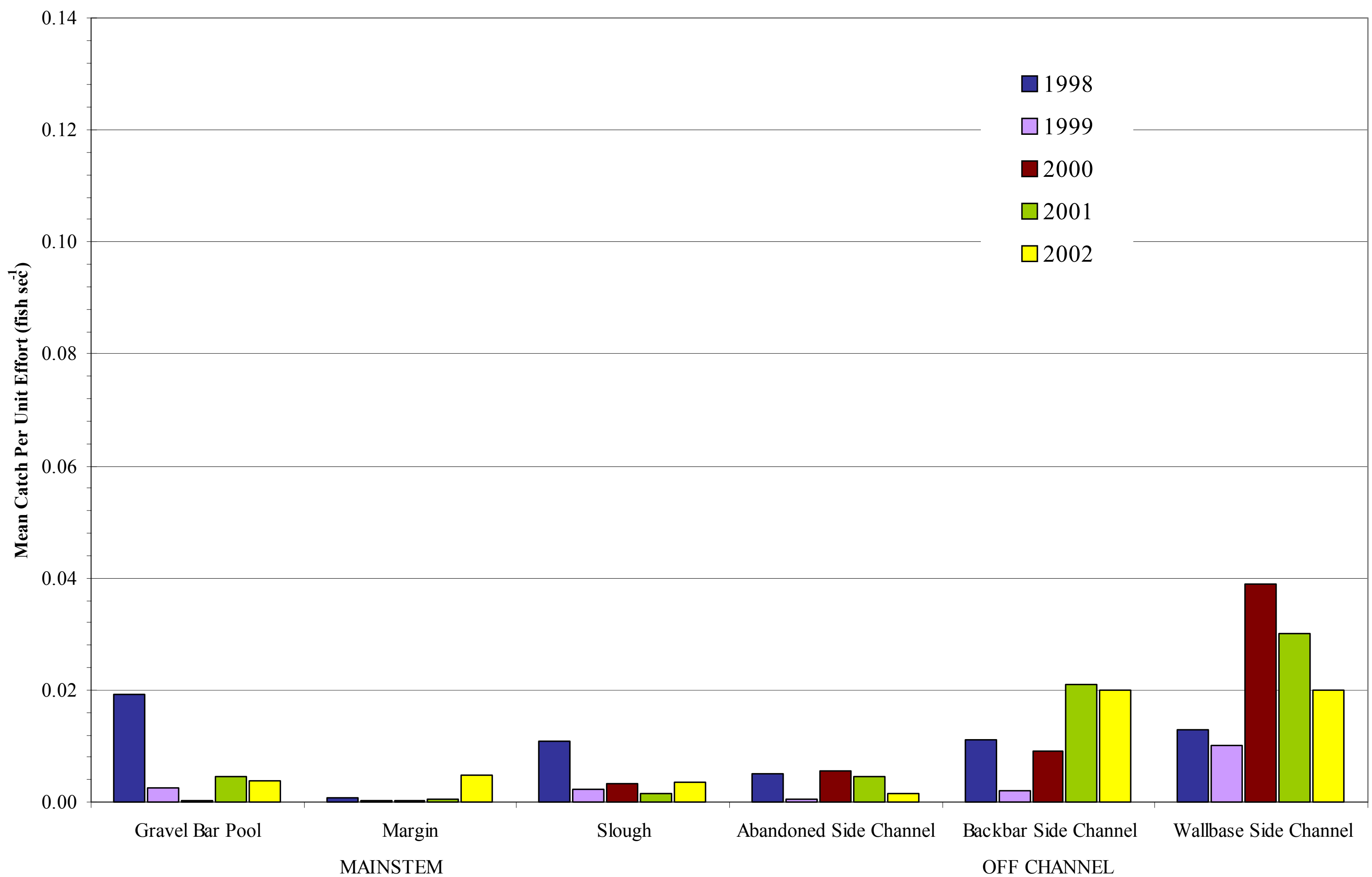

Figure 6. Average age-1+ juvenile salmonid catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

Chinook Salmon

Overall, age-0 Chinook salmon catch indices were not significantly different across the survey period (Chi-square Test = 4.67; P = 0.3232) or survey strata (Mann Whitney Rank Sum Test; T = 35.0, P = 0.5752) (Figure 7). Total age-0 Chinook catch were significantly greater in mainstem habitats when compared to off-channel habitats over the 1998-2002 study period (Mann Whitney Rank Sum Test; T = 143.0, P < 0.0001). Meaningful catch statistics could not be derived from age-1+ Chinook because of low catch numbers (N = 24; < 0.5% of Chinook catch) (Table 3); however, all age-1 were captured in mainstem margin habitat. Age-0 Chinook salmon catch indices were significantly greater within individual habitat strata (Table 6). The most notable differences occurred within mainstem gravel bar pools, which had significantly greater numbers of Chinook salmon when compared to the other five habitat strata (Table 6). Mainstem margin age-0 Chinook salmon catch indices were significantly higher in complex margin habitat compared to simple or unvegetated margins (Mann Whitney Rank Sum Test; T = 15.0, P = 0.0079). Differences within habitat strata were not significant within individual study seasons or survey strata due to large annual variances of catch indices.

Table 6. Student-Newman-Keuls pairwise multiple comparison test (+ = P<0.05; - = P>0.05) of age-0 Chinook salmon capture indices by habitat strata from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002 (mgbp = gravel bar pool; mm = margin; ms = slough; asc = abandoned side channel; bbsc = backbar side channel; wbsc = wallbase side channel).

Habitat Strata Comparison	Multiple Comparison Test
mgbp vs. wbsc	+
mgbp vs. asc	+
mgbp vs. bbsc	+
mgbp vs. ms	+
mgbp vs. mm	+
mm vs. wbsc	+
mm vs. asc	-
mm vs. bbsc	-
mm vs. ms	-
ms vs. wbsc	+
ms vs. asc	-
ms vs. bbsc	-
bbsc vs. wbsc	+
bbsc vs. absc	-
asc vs. wbsc	+

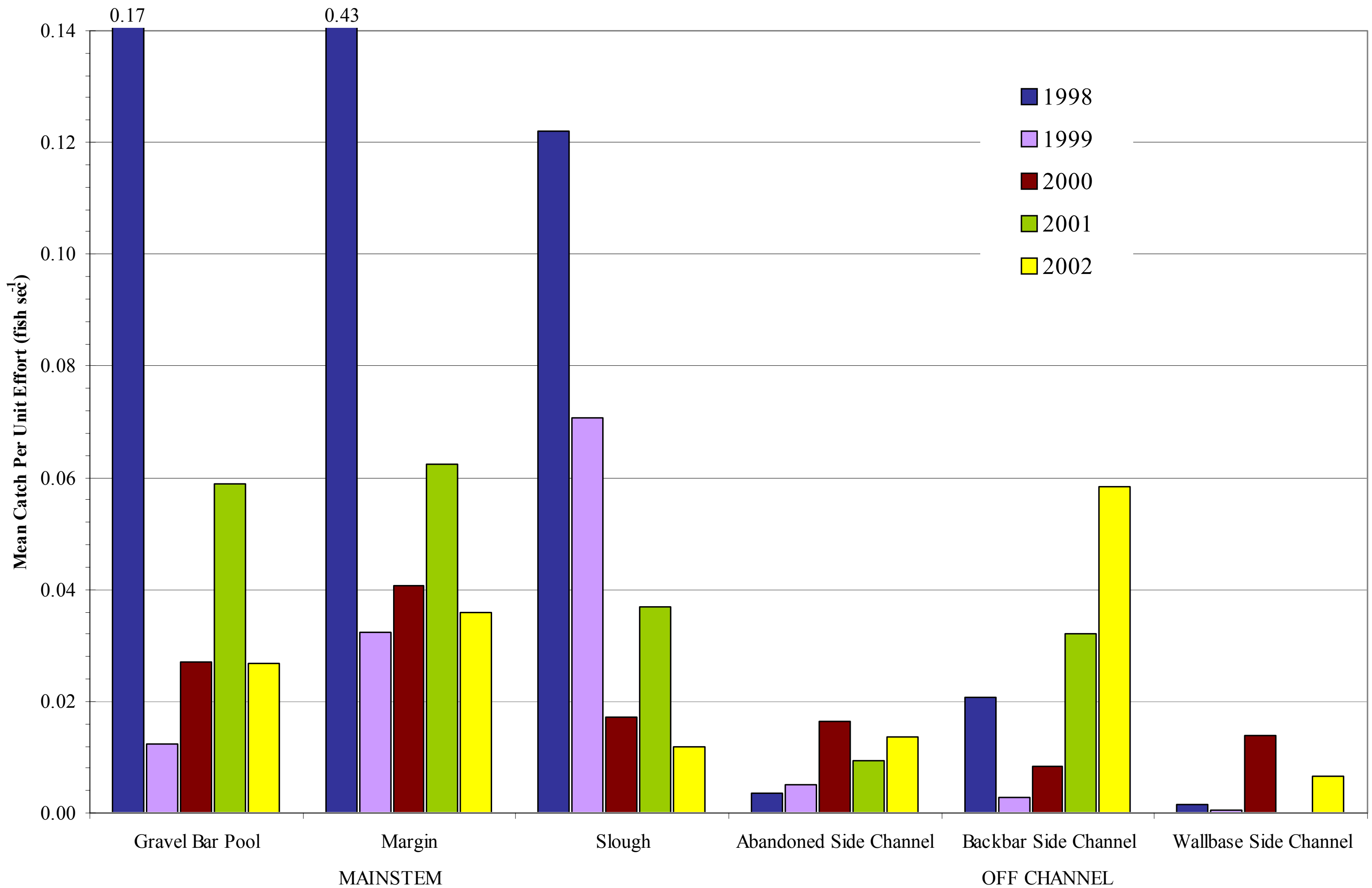

Figure 7. Average Chinook salmon catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

Coho Salmon

Overall, juvenile coho salmon catch indices were not significantly different across the survey period (Chi-square Test = 7.13; P = 0.1023) or survey strata (Mann Whitney Rank Sum Test; T = 29.0, P = 0.1596). Mean age-0 coho catch indices did not vary significantly across mainstem and off-channel habitats over the 1998-2002 study period (Mann Whitney Rank Sum Test; T = 226.0, P < 0.8035) (Figure 8). However, age-1+ coho catch indices (i.e., all species/age classes) were significantly greater in off-channel habitats compared to mainstem habitats (Mann Whitney Rank Sum Test; T = 296.0, P < 0.0090) (Figure 9; Table 7). The most notable differences occurred within wallbase and abandoned side channels, which generally contained significantly more age-1+ coho than other habitat strata (Table 7). Mainstem margin age-0 coho salmon catch indices were significantly higher in complex margin habitat compared to simple or unvegetated margins (Mann Whitney Rank Sum Test; T = 19.0, P = 0.0131); this difference was not apparent with age-1+ coho. Like Chinook salmon, differences within habitat strata were not significant within study season or survey strata due to large annual variances of catch indices.

Table 7. Student-Newman-Keuls pairwise multiple comparison test (+ = P<0.05; - = P>0.05) of age-1+ coho salmon capture indices by habitat strata from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002 (mgbp = gravel bar pool; mm = margin; ms = slough; asc = abandoned side channel; bbsc = backbar side channel; wbsc = wallbase side channel).

Habitat Strata Comparison	Multiple Comparison Test
wbsc vs. ms	+
wbsc vs. mgbp	+
wbsc vs. mm	+
wbsc vs. bbsc	+
wbsc vs. absc	+
asc vs. ms	+
absc vs. mgbp	+
asc vs. mm	+
asc vs. bbsc	+
bbsc vs. ms	-
bbsc vs. mgbp	-
bbsc vs. mm	-
mm vs. ms	-
mm vs. mgbp	-
mgbp vs. ms	-

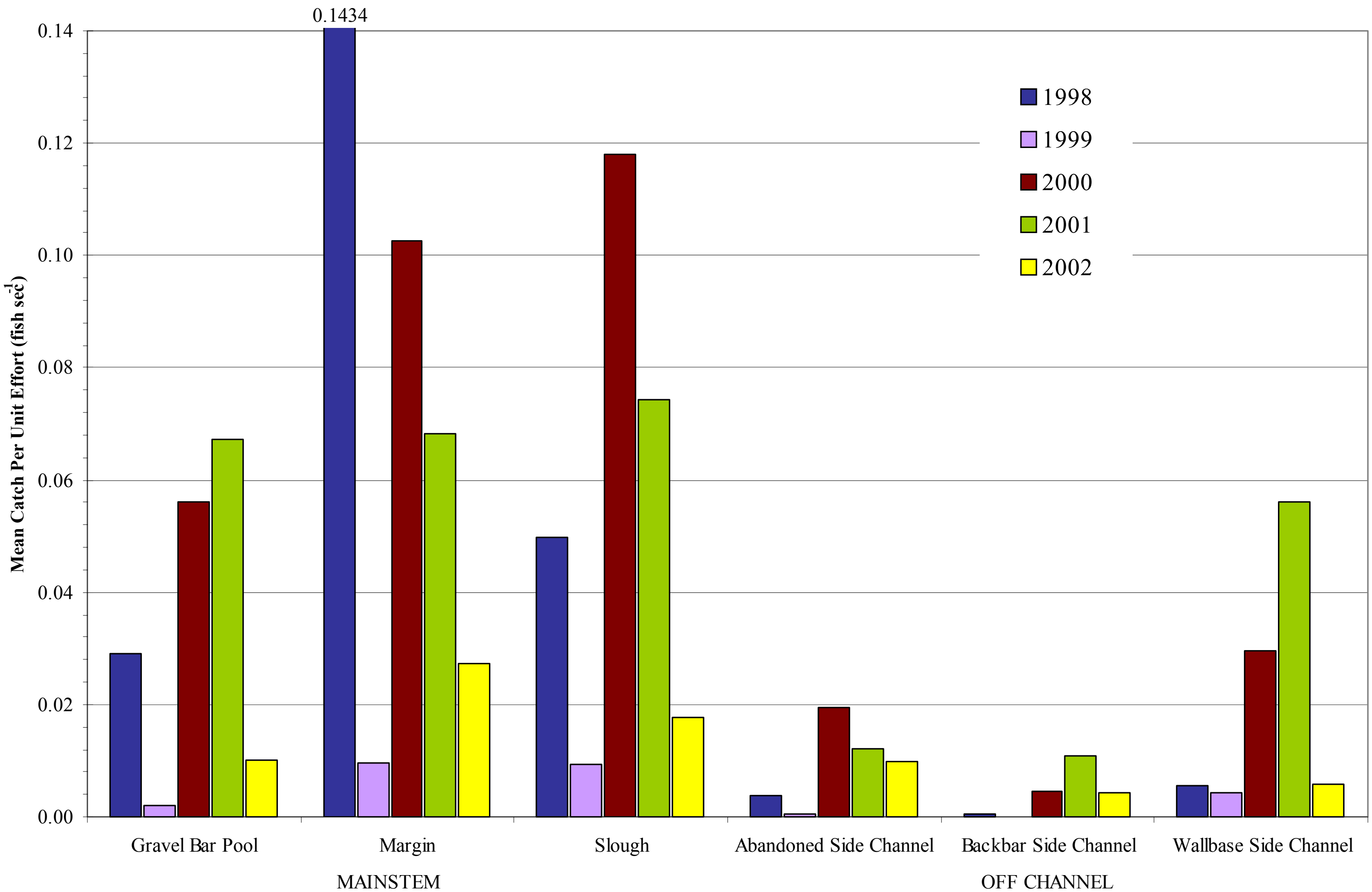

Figure 8. Average age-0 coho salmon catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

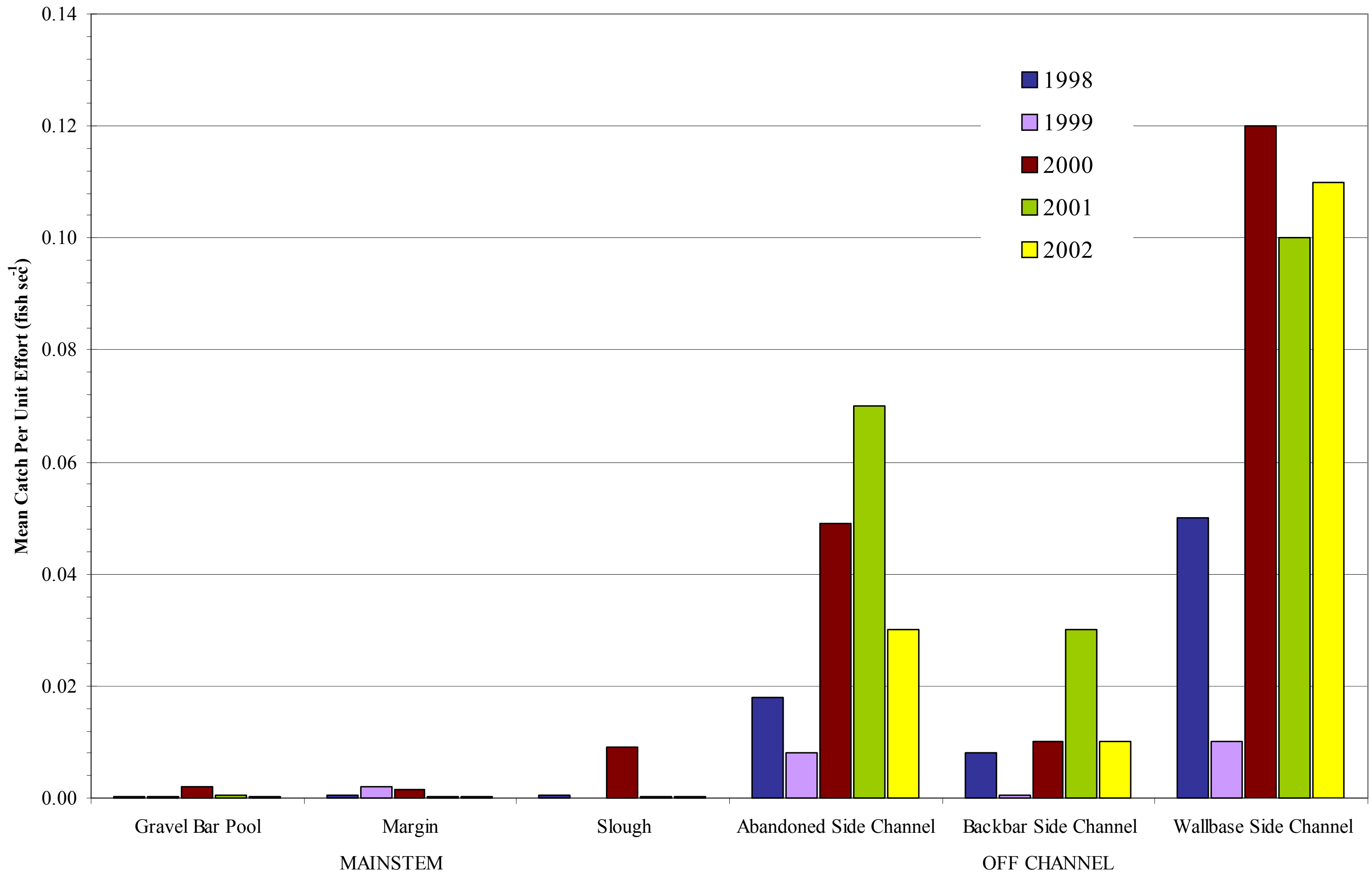

Figure 9. Average age-1+ coho salmon catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

Chum Salmon

Overall, juvenile chum catch indices were not significantly different across the survey period (Chi-square Test = 5.93; P = 0.7832) or survey strata (Mann Whitney Rank Sum Test; T = 23.0, P = 0.4213) (Figure 10). There was not a significant difference between mainstem and off-channel habitats over the 1998-2002 study period (Mann Whitney Rank Sum Test; T = 189.0, P < 0.0745). Mainstem margin age-0 chum salmon catch indices were significantly higher in complex margin habitat compared to simple or unvegetated margins (Mann Whitney Rank Sum Test; T = 45.0, P = 0.0029). Similar to coho and Chinook, differences within habitat strata were not significant within individual study seasons or survey strata due to large annual variances of catch indices.

Rainbow Trout

Overall, juvenile rainbow trout catch indices were not significantly different across the survey period (Chi-square Test = 1.20; P = 0.0031), but varied significantly throughout survey strata. Mainstem strata contained significantly more juvenile rainbow trout when compared to off-channel habitats (Mann Whitney Rank Sum Test; T = 33.0, P = 0.2144). Within age classes, mean age-0 rainbow trout catch indices were significantly greater in mainstem when compared to off-channel habitats over the 1998-2002 study period (Mann Whitney Rank Sum Test; T = 286.0, P = 0.0029) (Figure 11). Likewise, age-1+ coho catch indices were significantly greater in mainstem habitats compared to off-channel habitats (Mann Whitney Rank Sum Test; T = 333.0, P < 0.0001) (Figure 12). Habitat strata pairings generally followed the same pattern amongst age-0 and age-1+ rainbow trout whereby utilization of mainstem habitats was greater when compare to off-channel habitat (Table 8). Complex and unvegetated mainstem margin habitats contained similar numbers of age-0 rainbow trout (Mann Whitney Rank Sum Test; T = 31.0, P = 0.5481) and age-1 rainbow trout (Mann Whitney Rank Sum Test; T = 27.0, P = 0.9587).

Table 8. Student-Newman-Keuls pairwise multiple comparison test (+ = P<0.05; - = P>0.05) of age-0 and age-1+ rainbow trout capture indices by habitat strata from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002 (mgbp = gravel bar pool; mm = margin; ms = slough; asc = abandoned side channel; bbsc = backbar side channel; wbsc = wallbase side channel).

Habitat Strata Comparison	Age 0 Multiple Comparison Test	Age-1+ Multiple Comparison Test
mm vs. wbsc	+	+
mm vs. asc	+	+
mm vs. bbsc	-	+
mm vs. mgbp	-	-
mm vs. ms	-	-
ms vs. wbsc	+	+
ms vs. asc	+	+
ms vs. bbsc	-	+
ms vs. mgbp	-	-
mgbp vs. wbsc	+	+
mgbp vs. asc	+	+
mgbp vs. bbsc	-	+
bbsc vs. wbsc	+	+
bbsc vs. asc	+	-
asc vs. wbsc	-	+

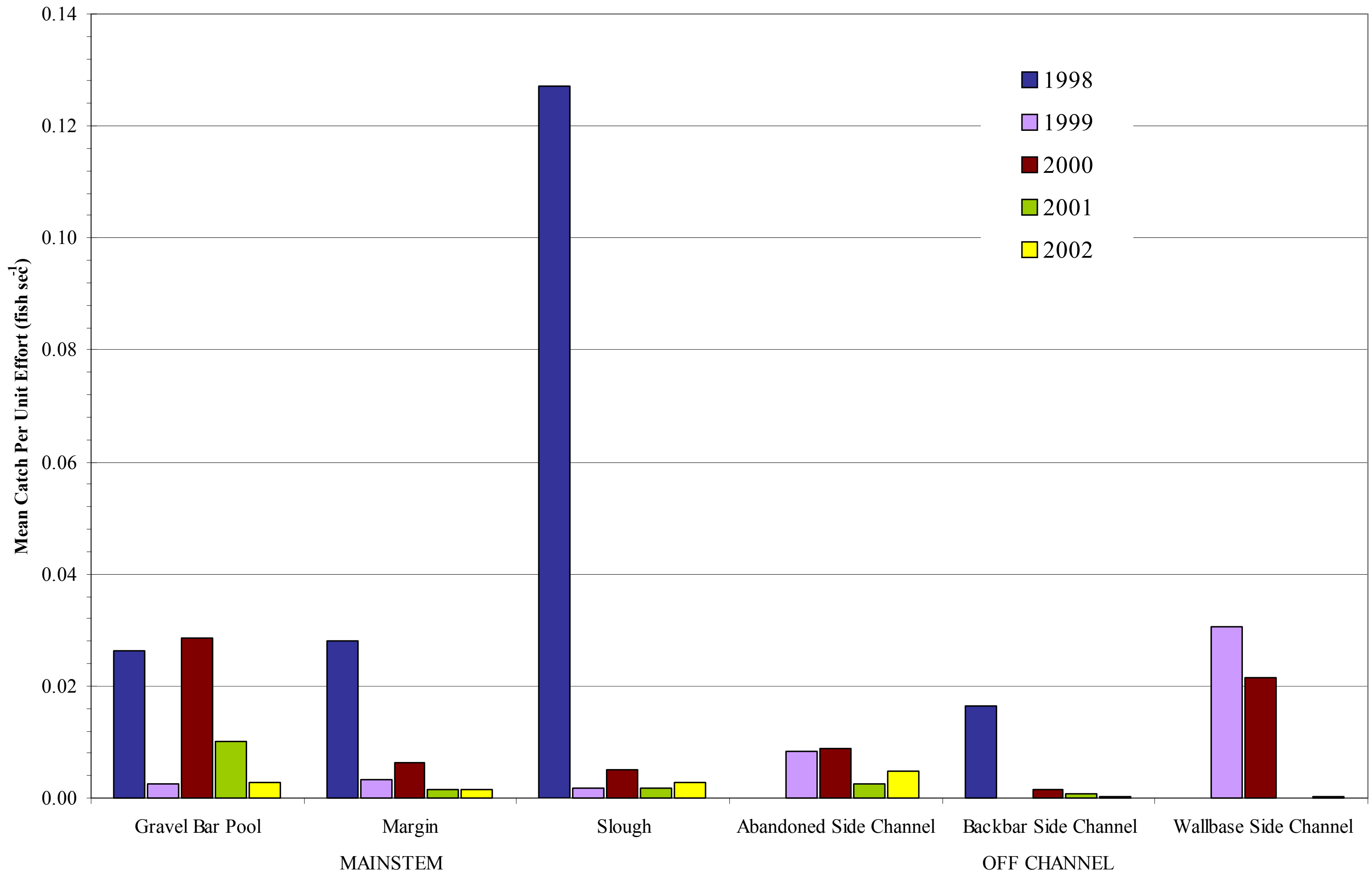

Figure 10. Average age-0 chum salmon catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

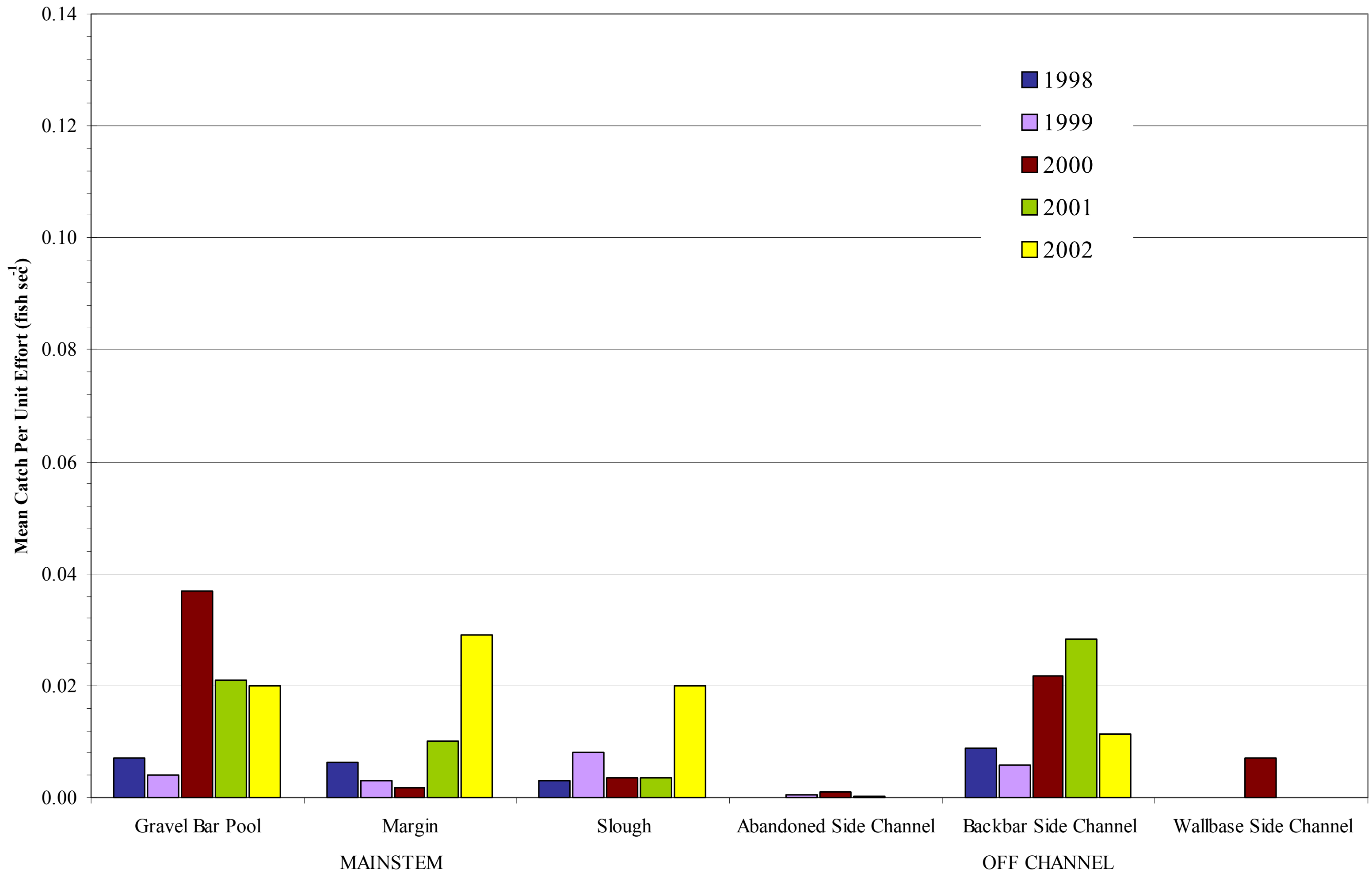

Figure 11. Average age-0 rainbow trout catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

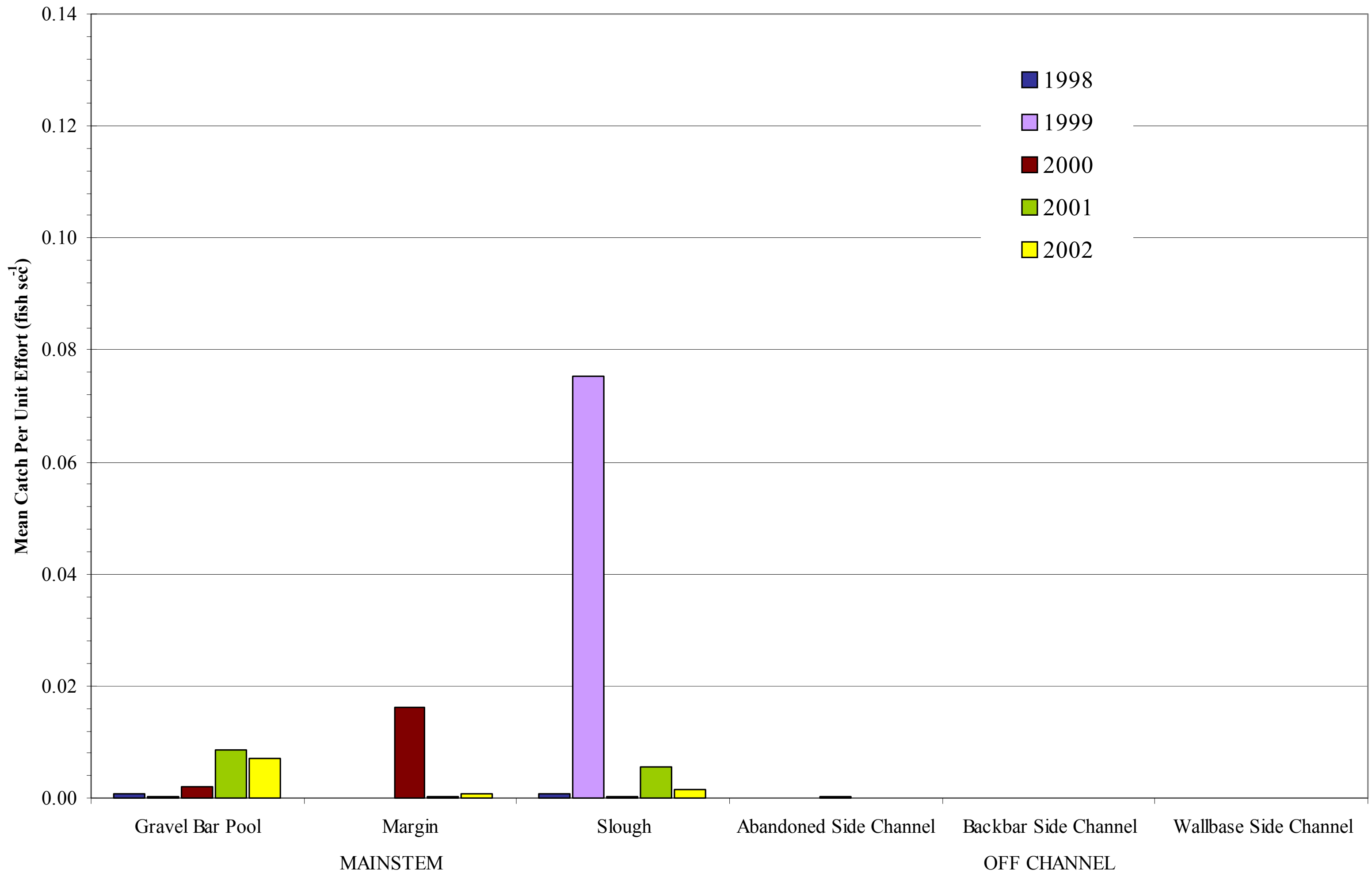

Figure 12. Average age-1+ rainbow trout catch indices (fish·sec^{-1}) from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

4.1.3 Chinook Salmon Periodicity and Size

Age-0 Chinook salmon periodicity varied over the study period (Figure 13). Peak Chinook abundance typically occurred by 14 April (Figure 14), but was as late as 14 May (e.g., 1999 and 2000) and 28 May (e.g., 2001). Age-0 Chinook were present in the middle Green River during the initial survey date during each study period, and continued to reside in lateral habitats until the end of June in most study years (Figures 12-13). Juvenile Chinook salmon emergence was typically complete (99% fry had absorbed yolk sac) by 28 May (Figure 15) at which time the occurrence frequency of age-0 Chinook was starting to decrease in the middle Green River. Emergence, frequency of occurrence, and peak abundance of Chinook salmon was generally two weeks later the upstream-most sites (sites located immediately downstream from the Headworks). Recapture of age-0 Chinook salmon was infrequent (<1%) during the study period. Mean length of Chinook after emergence was 40.3 (std. dev. = 1.5) mm FL, increasing rapidly throughout their residence in the middle Green River (Table 9). Individuals recaptured in off-channel habitats were larger compared to mainstem habitats, but the difference was not significant due to variation from low recapture numbers (Mann Whitney Rank Sum Test; $T = 35.0$, $P = 0.0914$).

Table 9. Age-0 Chinook salmon monthly average fork lengths (std. dev. in parenthesis) by study year from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002.

Survey Month	1998	1999	2000	2001	2002
February	40.8(5.4)	41.2(1.8)	41.9(2.2)	41.6(2.8)	40.3(1.4)
March	41.8(7.1)	44.8(2.6)	45.6(4.9)	42.1(2.2)	41.6(2.9)
April	46.7(7.8)	48.4(9.2)	46.4(10.7)	45.5(4.6)	43.2(3.5)
May	55.9(19.0)	64.0(8.7)	64.4(10.2)	54.4(8.4)	48.1(8.9)
June	64.4(19.0)	73.5(11.2)	72.0(6.1)	68.2(7.5)	61.1(9.9)
July	-	-	-	75.1(10.3)	72.4(11.1)

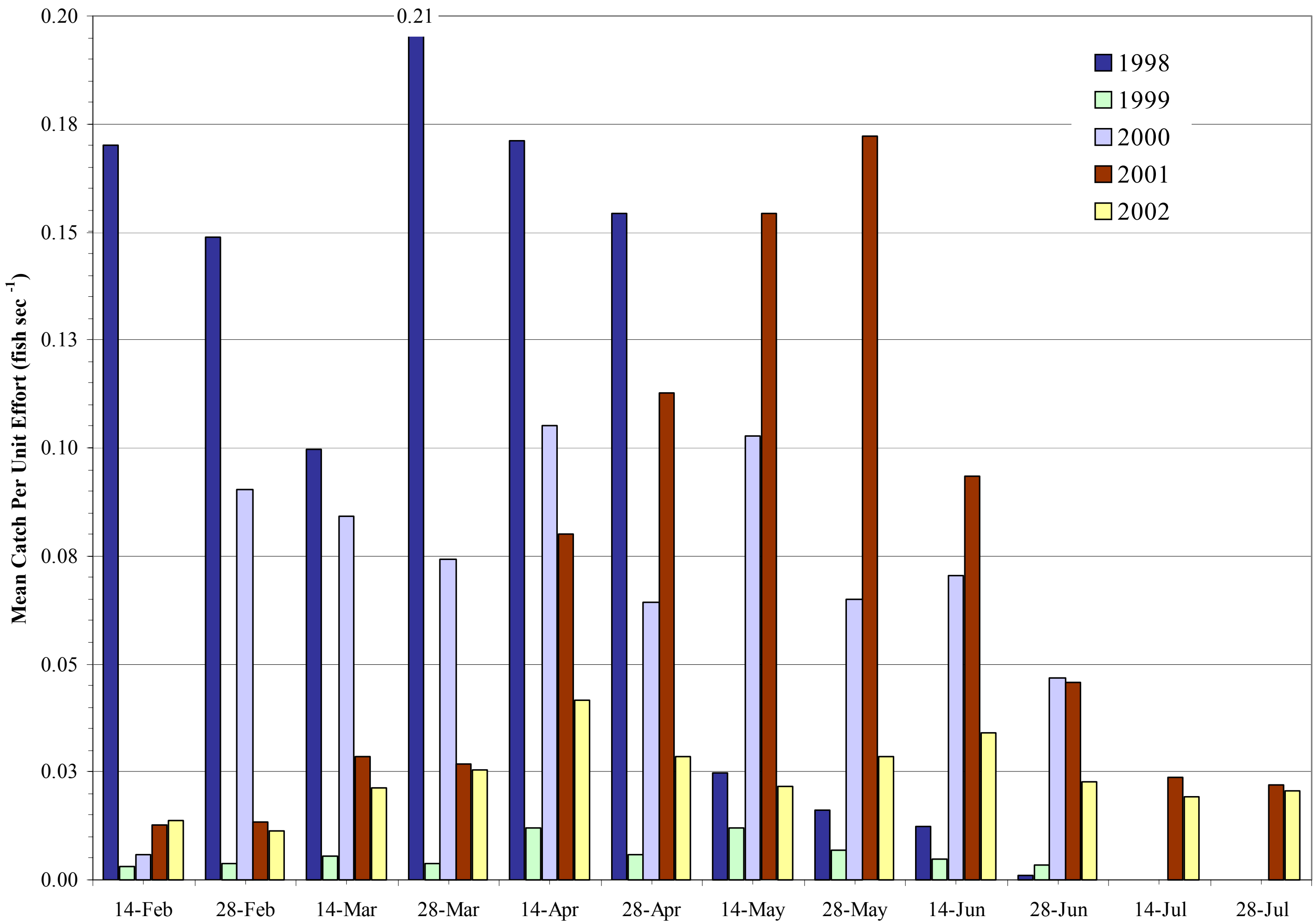

Figure 13. Age-0 Chinook salmon catch indices (fish·sec^{-1}) from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

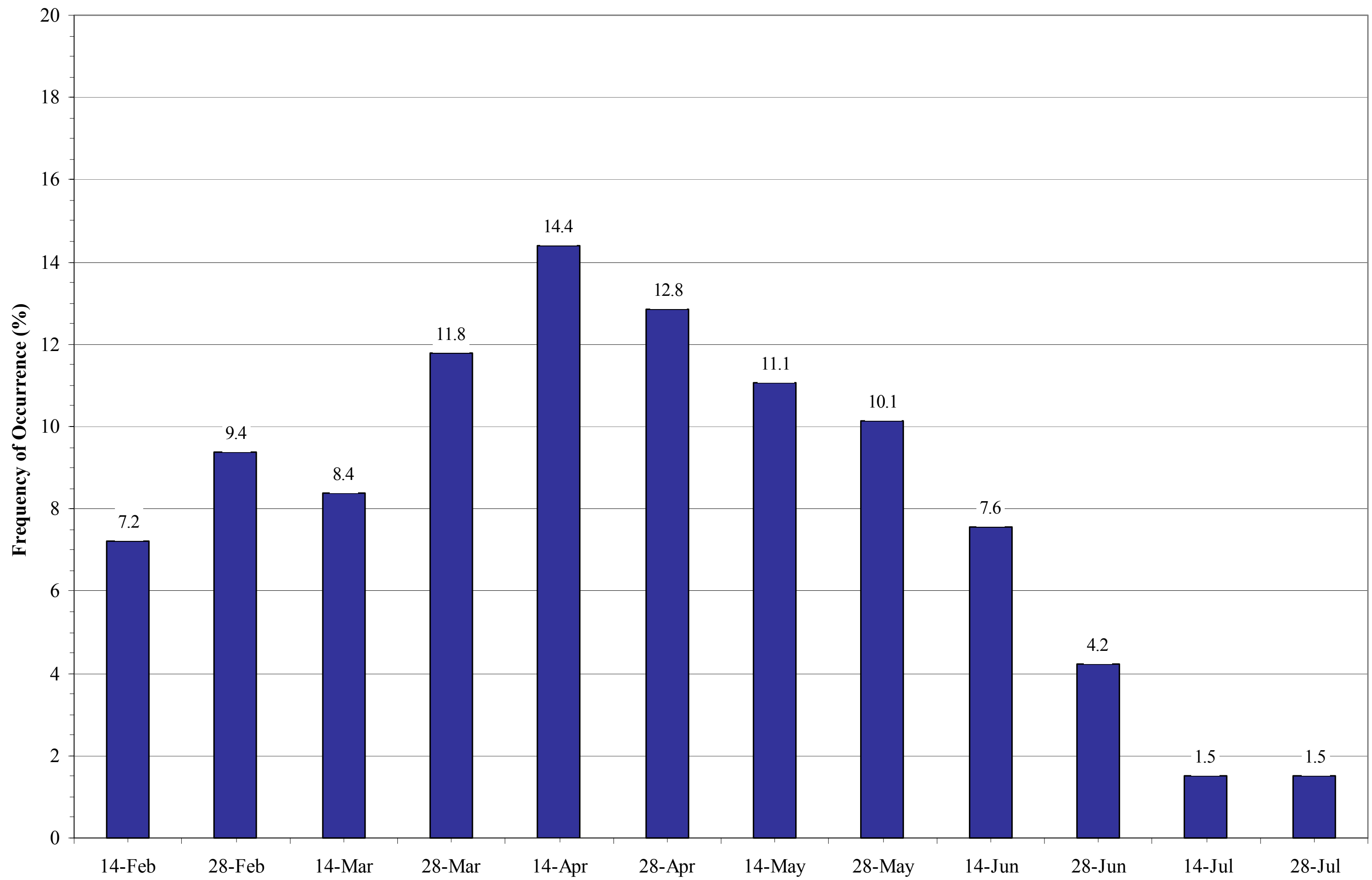

Figure 14. Age-0 Chinook salmon occurrence frequency from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

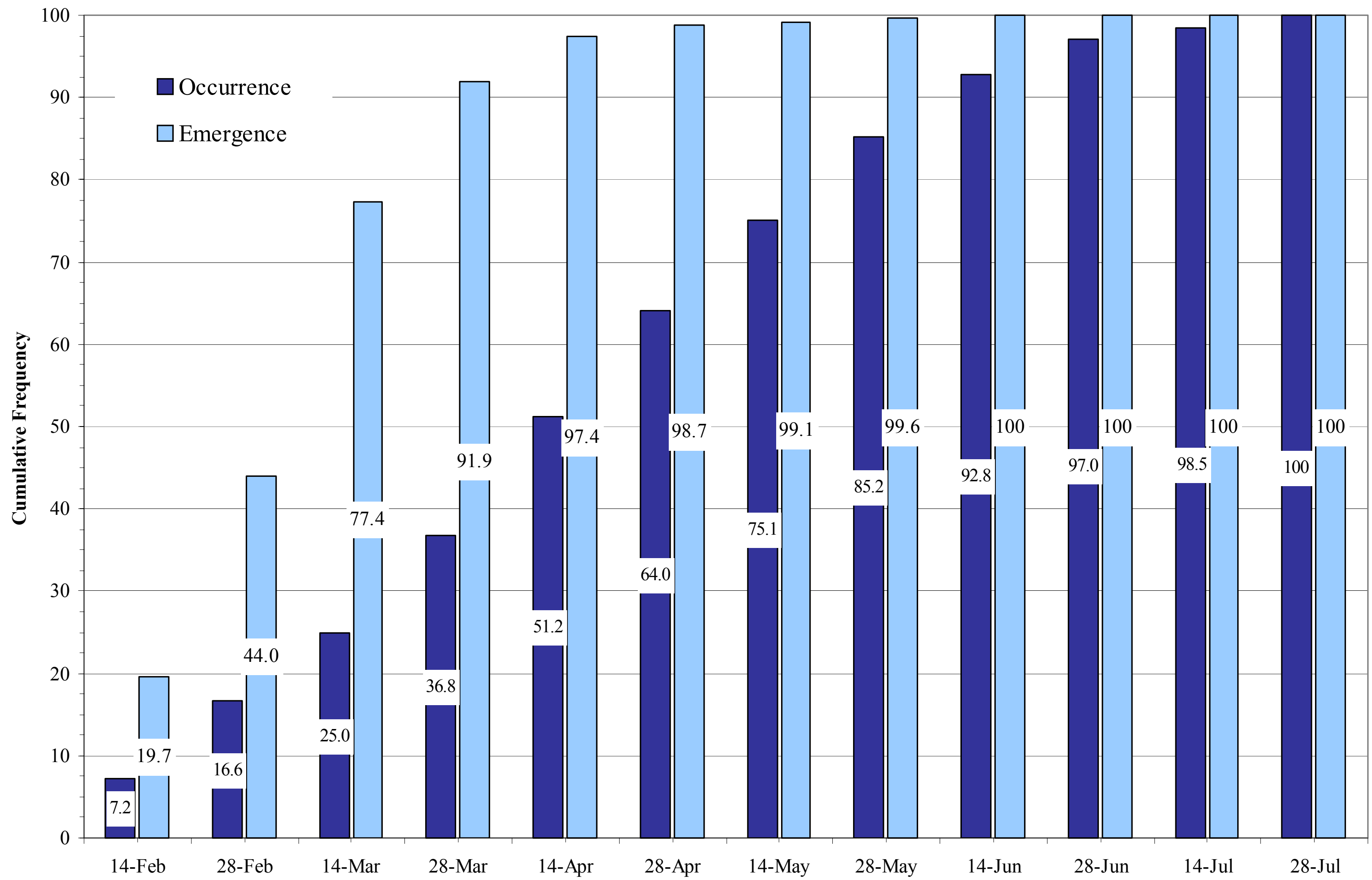

Figure 15. Cumulative age-0 Chinook salmon occurrence and emergence frequencies from mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

4.1.4 Coho Salmon Periodicity and Size

Age-0 coho salmon periodicity was much more consistent over the study period than that of Chinook (Figure 16). Peak coho abundance typically also occurred by 14 April (Figure 15), but was much less variable between study years. Age-0 coho were typically not present until late February and remained until the final surveys were conducted in July; while age-1+ coho were present early in February and presumably moved downstream by the end of May in most study years (Figures 16-17). Juvenile coho salmon emergence was typically complete (99% fry had absorbed yolk sac) by the middle of June (Figure 18). Like Chinook, the emergence, frequency of occurrence, and peak abundance of coho salmon was generally two weeks later the upstream-most sites (sites located immediately downstream from the Headworks). Recapture of age-1 coho salmon was frequent (20% of total) during the study period. Mean length of coho shortly after emergence was 38.1 (std. dev. = 0.9) mm FL, increasing rapidly throughout their residence in the middle Green River (Tables 10-11). Age-1+ coho recaptured in off-channel habitats were larger compared to mainstem habitats (Mann Whitney Rank Sum Test; T = 40.0, P = 0.00794).

Table 10. Age-0 coho salmon monthly average fork lengths (std. dev. in parenthesis) by study year from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002.

Survey Month	1998	1999	2000	2001	2002
February	36.8(2.4)	38.1(0.7)	38.0(1.9)	34.3(1.3)	36.1(2.7)
March	39.2(4.3)	38.2(2.0)	38.8(5.8)	35.7(1.7)	38.8(4.1)
April	41.6(6.1)	41.9(5.4)	42.9(5.3)	36.9(2.9)	42.2(6.1)
May	50.4(7.2)	53.4(6.9)	51.5(7.4)	42.6(5.1)	51.2(8.8)
June	60.6(8.9)	65.1(7.8)	67.1(9.2)	49.8(6.4)	60.7(9.3)
July	-	-	78.7(7.7)	67.5(6.9)	67.6(6.7)

Table 11. Age-1+ coho salmon monthly average fork lengths (std. dev. in parenthesis) by study year from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002.

Survey Month	1998	1999	2000	2001	2002
February	104.9(11.8)	100.3(13.3)	102.1(12.9)	86.1(9.7)	86.5(5.6)
March	105.1(12.4)	106.9(10.1)	106.6(12.2)	89.3(10.8)	87.3(8.1)
April	112.4(16.2)	118.4(7.6)	114.4(15.9)	99.3(14.8)	91.7(12.2)
May	112.8(15.7)	132.4(9.4)	122.6(10.1)	96.7(9.1)	97.5(14.7)
June			-		-
July			-		-

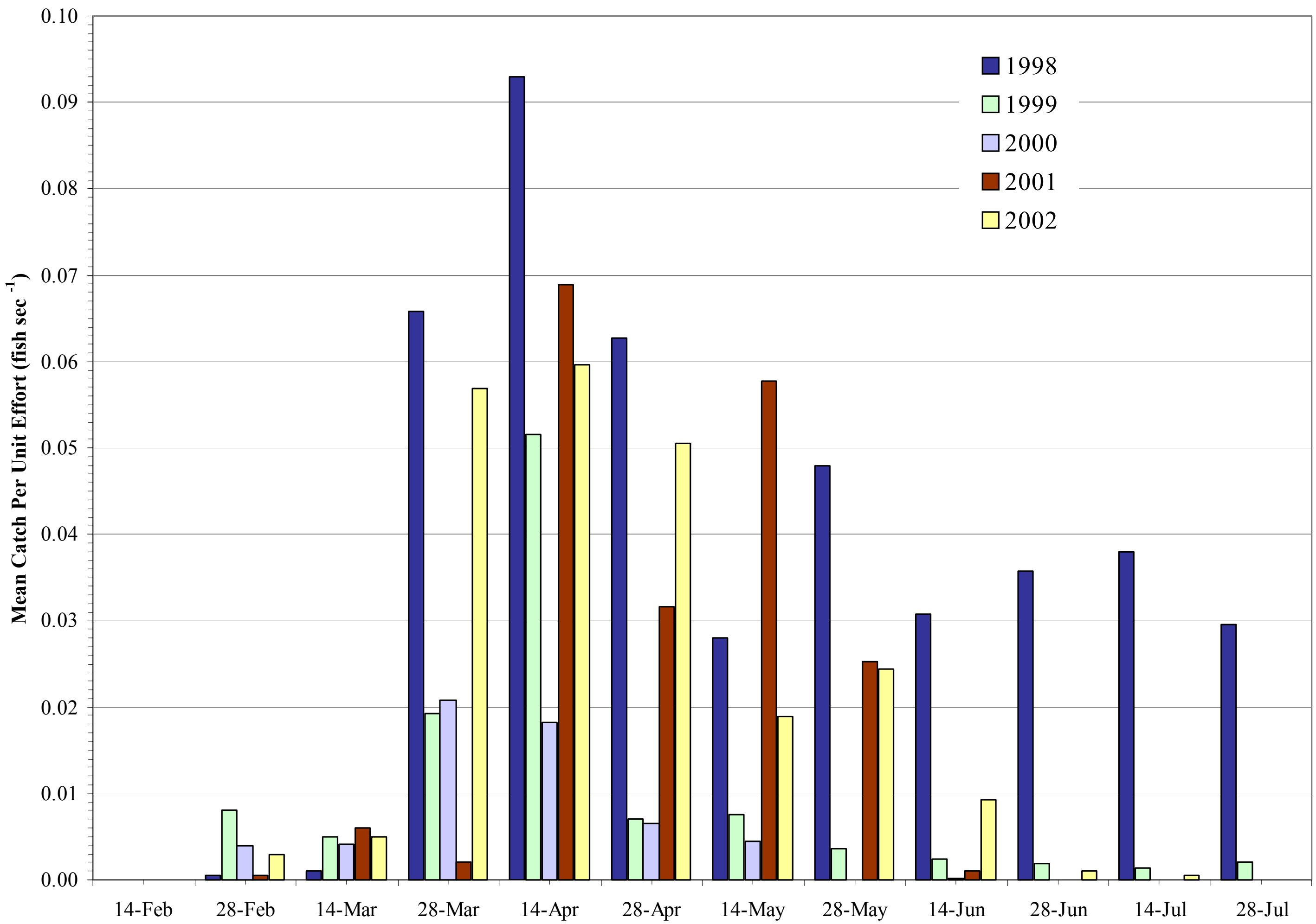

Figure 16. Age-0 coho salmon catch indices (fish·sec^{-1}) from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

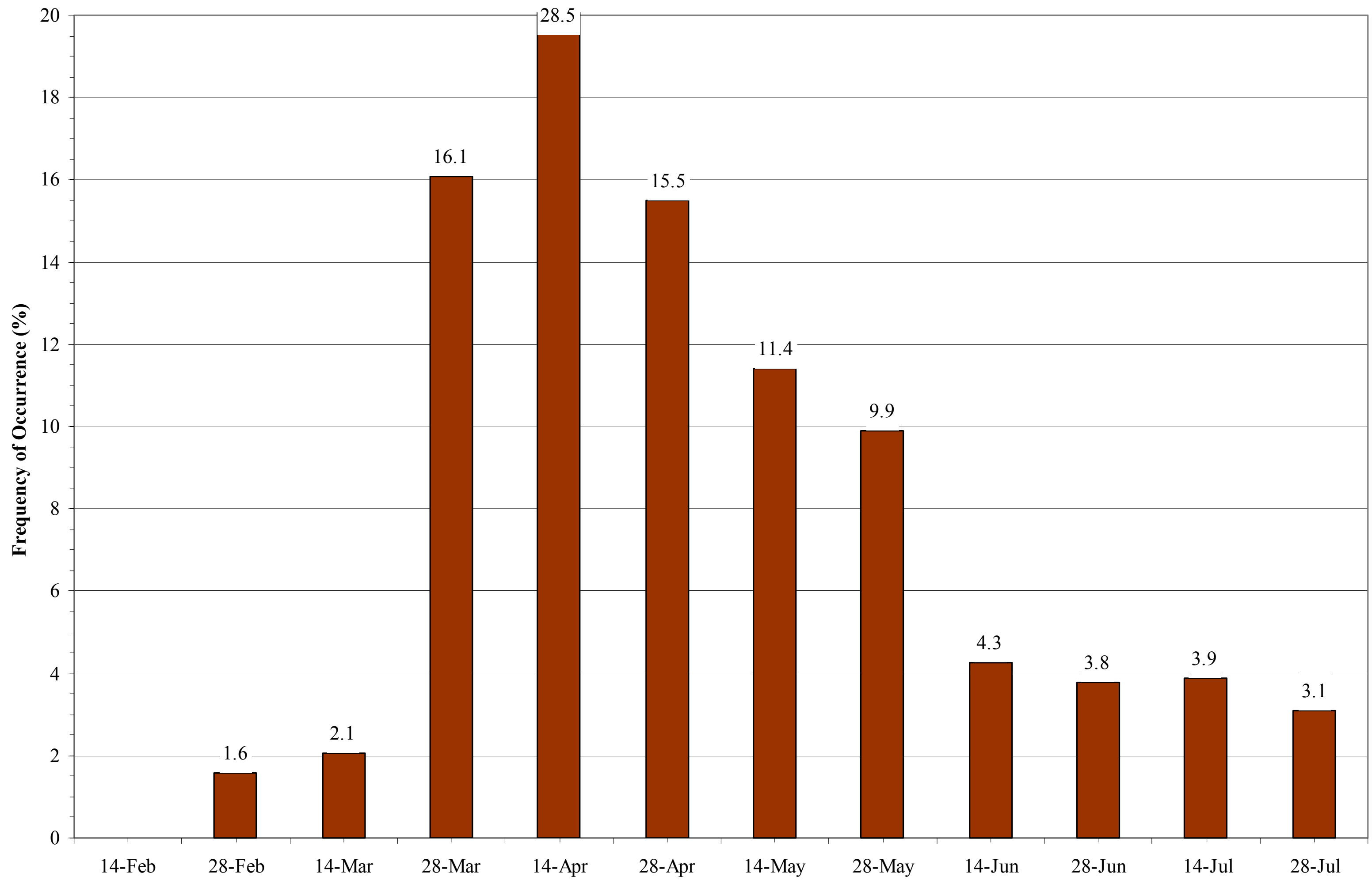

Figure 17. Age-0 coho salmon occurrence frequency from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

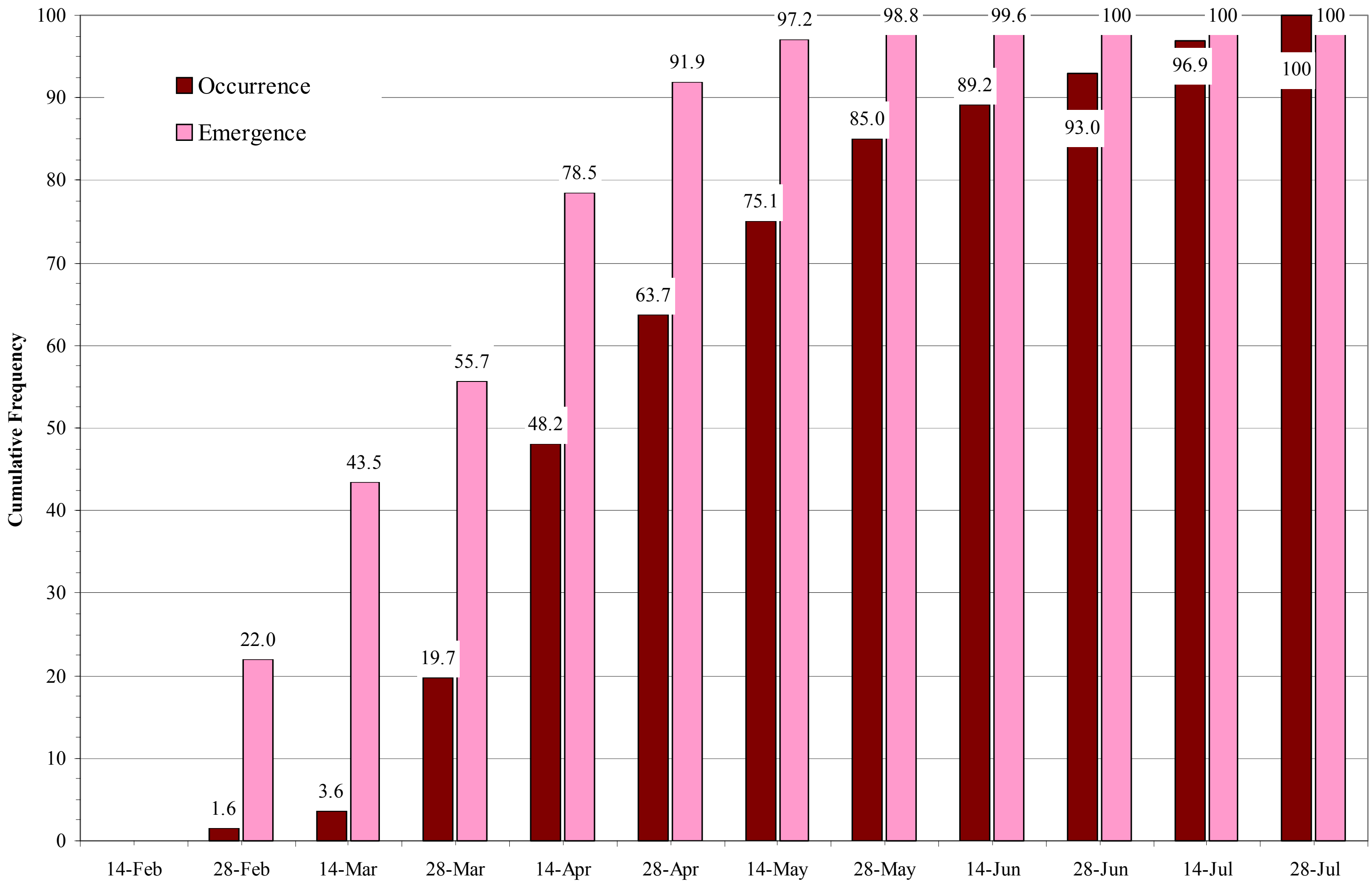

Figure 18. Cumulative age-0 coho salmon occurrence and emergence frequencies from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

4.1.5 Chum Salmon Periodicity and Size

Like coho, age-0 chum salmon periodicity was much more consistent than that for Chinook (Figure 19). Chum fry were not typically appearing in lateral habitats until late February, peaking in abundance in late March and early April (Figure 19-20). Age-0 chum moved out of the middle Green River generally by the end of May, with only a few larger individuals remaining in early June (Table 12; Figure 21). Like Chinook, juvenile chum salmon emergence was typically complete (99% fry had absorbed yolk sac) by late April (Figure 18). Chum fry were not present in the upstream-most sites (i.e., USGS and Pipeline sites). Due to their rapid movement downstream from the middle Green River, recapture of chum salmon fry was infrequent (<0.5% of total) during the study period. Mean length of chum shortly after emergence was 38.3 (std. dev. = 2.7) mm FL, and increased rapidly throughout their residence in the middle Green River (Table 12). The few age-0 chum recaptured in off-channel habitats were larger compared to mainstem habitat counterparts; however this difference was not significant due to infrequent recapture rates (Mann Whitney Rank Sum Test; T = 13.0, P = 0.1041).

Table 12. Age-0 chum salmon monthly average fork lengths (std. dev. in parenthesis) by study year from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002.

Survey Month	1998	1999	2000	2001	2002
February	37.5(1.4)	38.3(2.6)	38.1(1.9)	37.9(1.6)	37.9(2.1)
March	41.8(2.4)	41.1(3.3)	40.0(2.2)	38.1(1.9)	40.3(3.4)
April	44.1(4.3)	41.2(3.3)	41.1(3.7)	39.1(2.6)	42.4(2.6)
May	45.2(3.3)	43.7(3.2)	44.3(5.5)	44.9(5.7)	44.4(3.6)
June	-	56.7(5.3)	66.6(12.5)	-	-
July	-	-	-	-	-

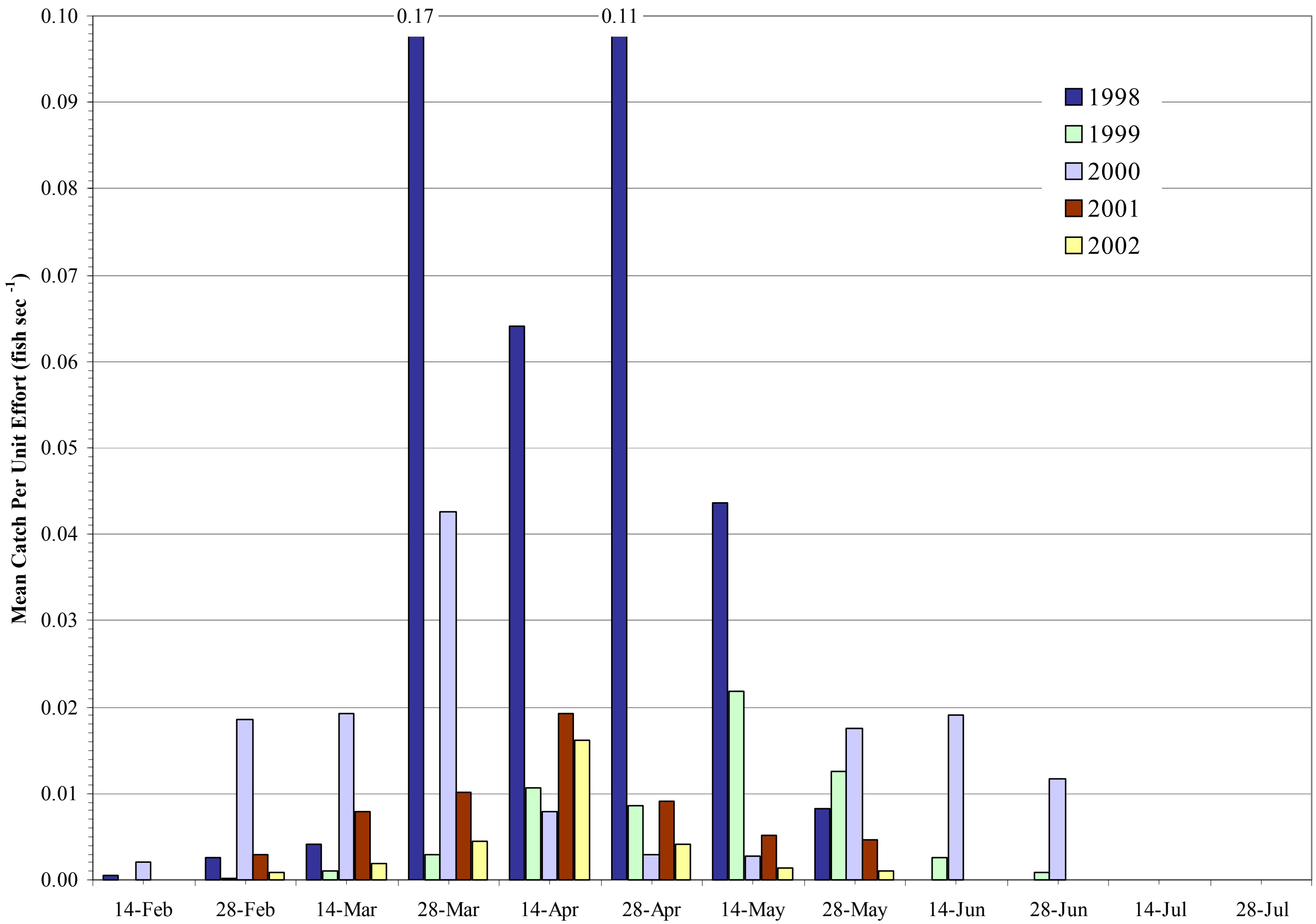

Figure 19. Age-0 chum salmon catch indices (fish·sec^{-1}) from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

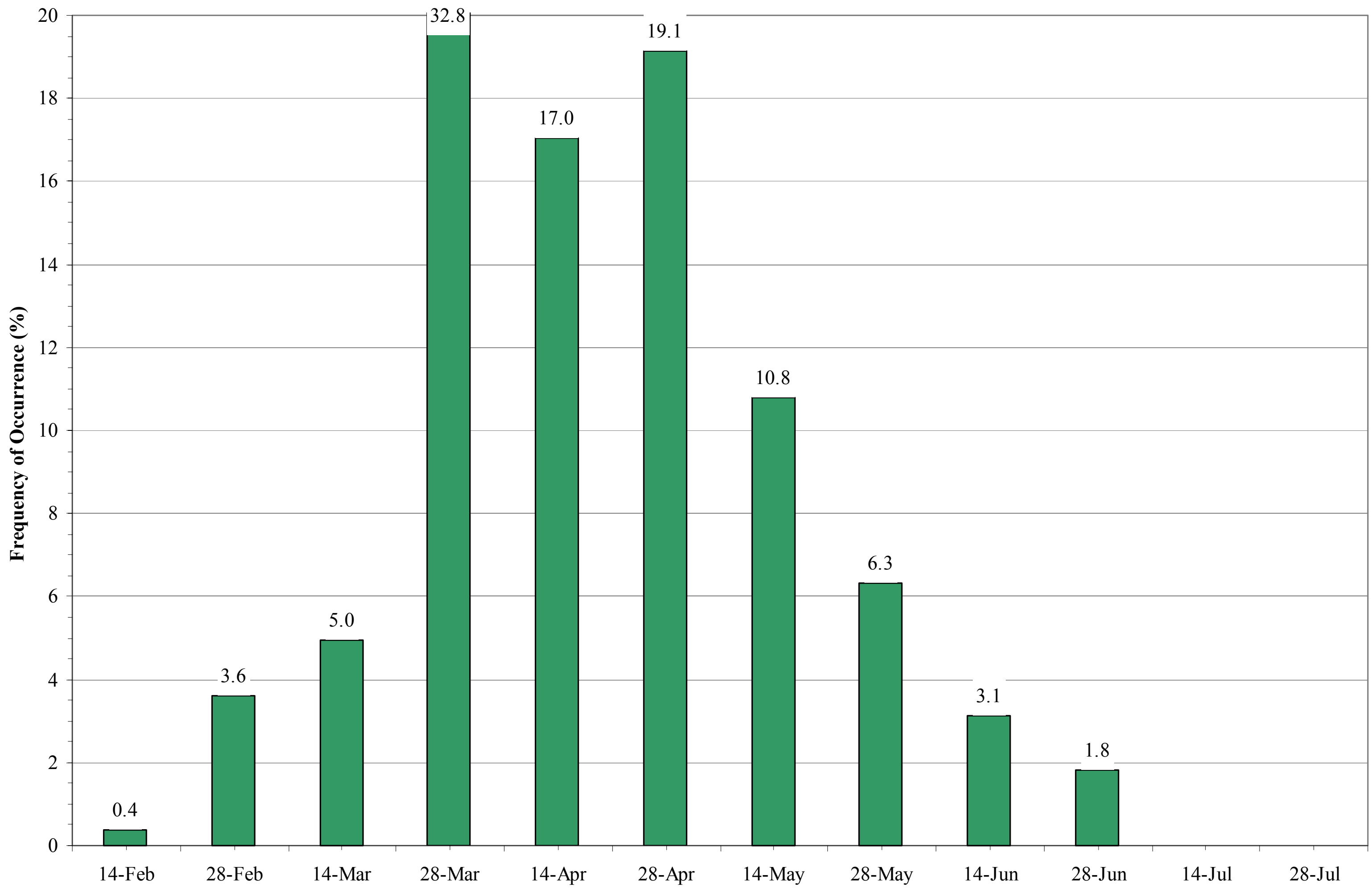

Figure 20. Age-0 chum salmon occurrence frequency from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

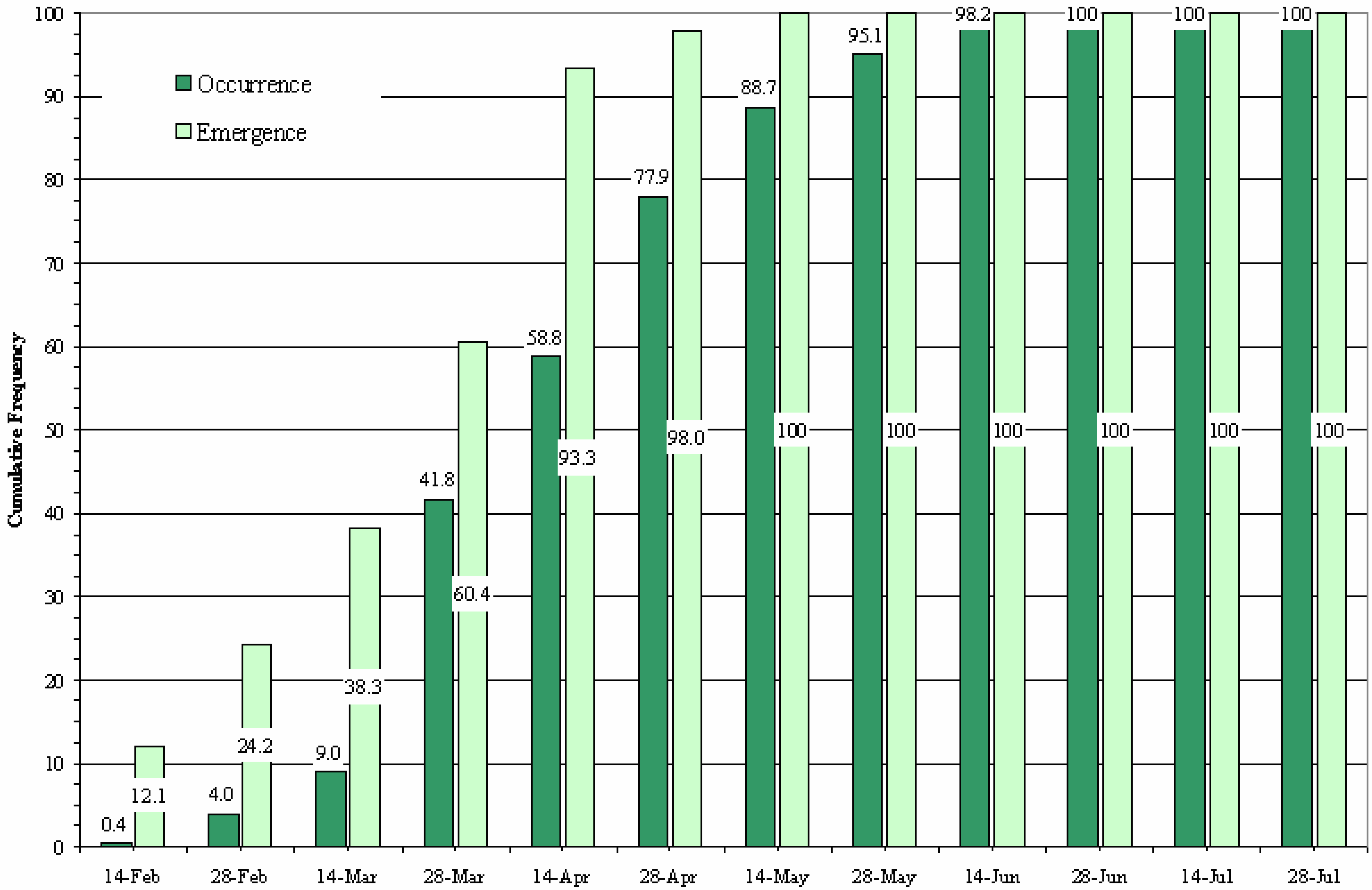

Figure 21. Cumulative age-0 chum salmon occurrence and emergence frequencies from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

4.1.6 Rainbow Trout Periodicity and Size

Rainbow trout were the latest emerging juvenile salmonid in the middle Green River (Figures 22-24). Peak age-0 rainbow trout abundance typically occurred shortly after emergence in late June and early July (Figure 23). Age-1+ rainbow trout were present throughout the survey period but were infrequently found in lateral habitats of the middle Green River; recapture rates (5%) was less than half of that witnessed for age-1 coho salmon. Juvenile rainbow trout emergence was the fastest of all species of juvenile salmonids, beginning in late May and typically complete (99% fry had absorbed yolk sac) by the end of June (Figure 24). Unlike Chinook and coho salmon, the emergence, frequency of occurrence, and peak abundance of rainbow trout typically occurred in symmetry between upstream and downstream site locations. The average fork length of rainbow trout shortly after emergence was 33.7 (std. dev. = 2.0) mm FL, increasing rapidly throughout their residence in the middle Green River (Tables 13-14).

Table 13. Age-0 rainbow trout monthly average fork lengths (std. dev. in parenthesis) by study year from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002.

Survey Month	1998	1999	2000	2001	2002
February	-	-	-	-	-
March	-	-	-	-	-
April	-	-	-	-	-
May	35.3(2.7)	33.5(6.4)	36.8(4.0)	34.1(1.5)	33.6(2.8)
June	37.9(6.1)	37.6(5.0)	35.6(4.8)	33.8(3.2)	34.4(6.2)
July	41.2(2.4)	42.4(4.9)	41.1(9.8)	38.5(6.1)	39.2(6.7)

Table 14. Age-1+ rainbow trout monthly average fork lengths (std. dev. in parenthesis) by study year from 22 juvenile salmonid electrofishing sites in the middle Green River, King County, Washington, 1998-2002.

Survey Month	1998	1999	2000	2001	2002
February	100.0(20.1)	100.6(24.9)	91.0(15.1)	91.9(25.2)	85.0(13.1)
March	110.0(23.2)	102.2(30.5)	91.4(17.9)	94.0(16.4)	98.8(18.4)
April	109.3(32.2)	109.5(16.5)	97.4(23.6)	102.6(15.3)	98.8(24.0)
May	117.2(32.9)	125.5(40.5)	104.9(23.6)	116.9(22.6)	113.9(17.8)
June	128.0(17.1)	129.0(19.5)	110.3(23.9)	126.5(16.4)	120.3(13.1)
July	-	-	126.6(24.6)	128.8(29.2)	122.2(31.6)

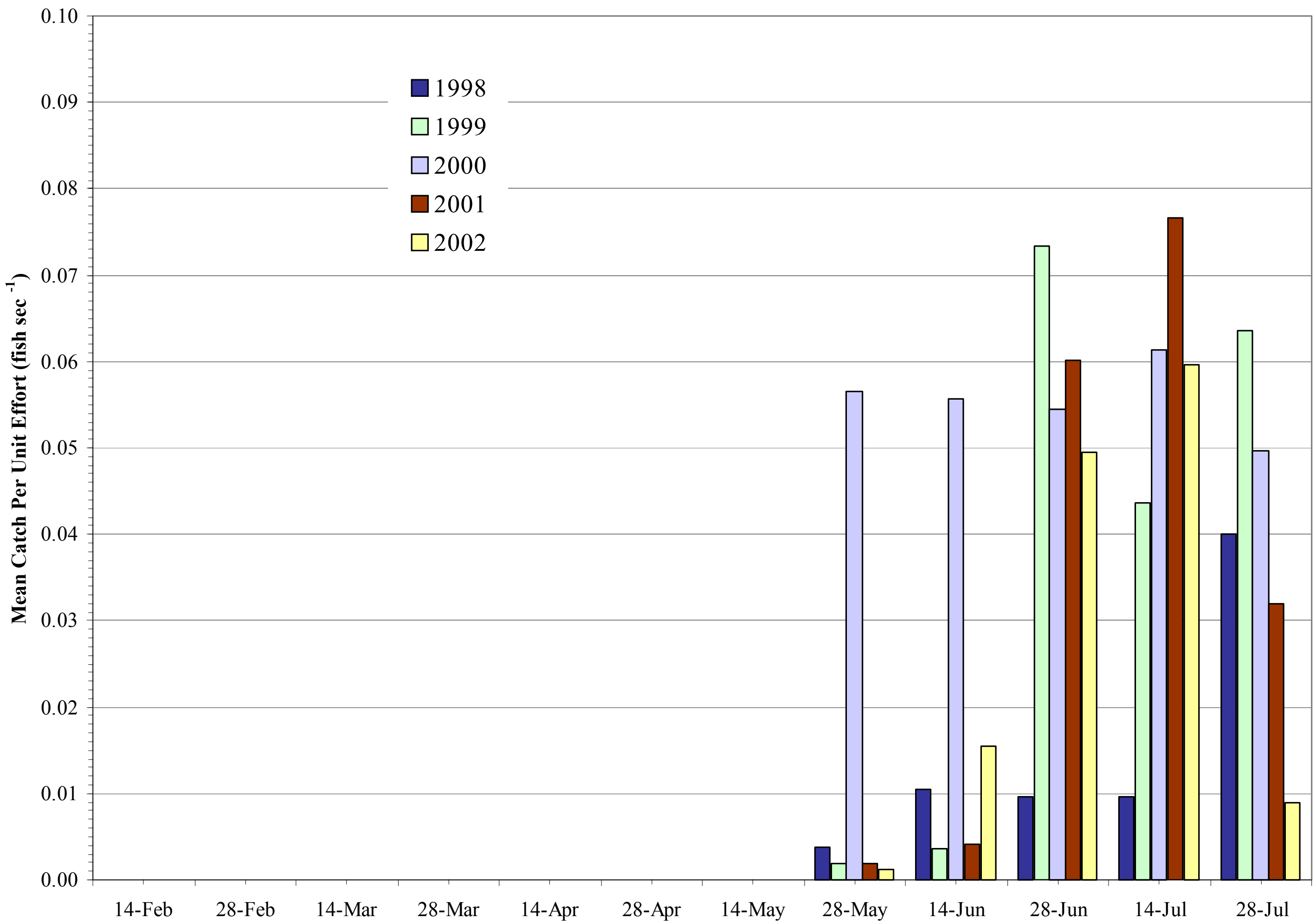

Figure 22. Age-0 rainbow trout catch indices (fish·sec^{-1}) from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

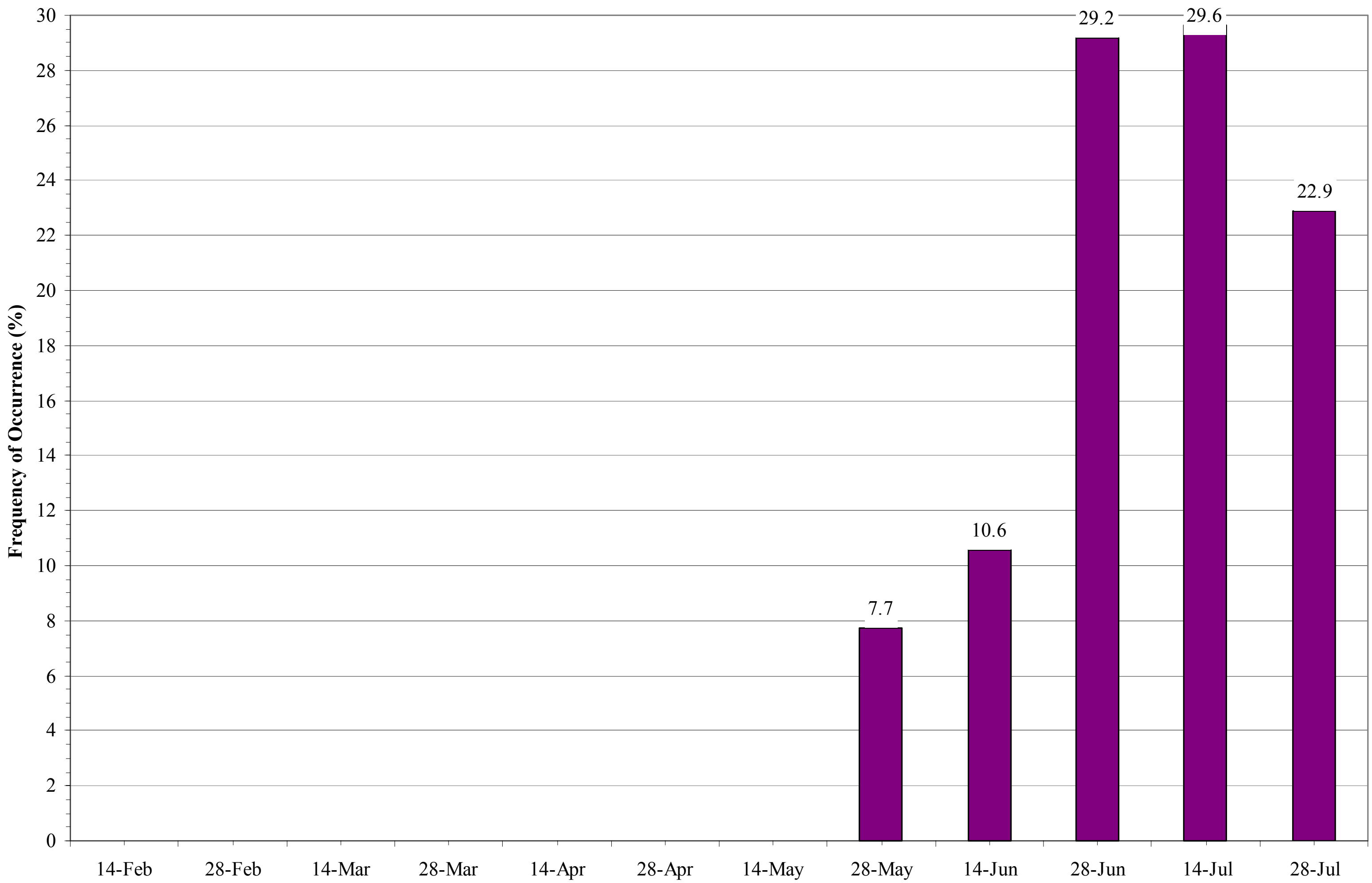

Figure 23. Age-0 rainbow trout occurrence frequency from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

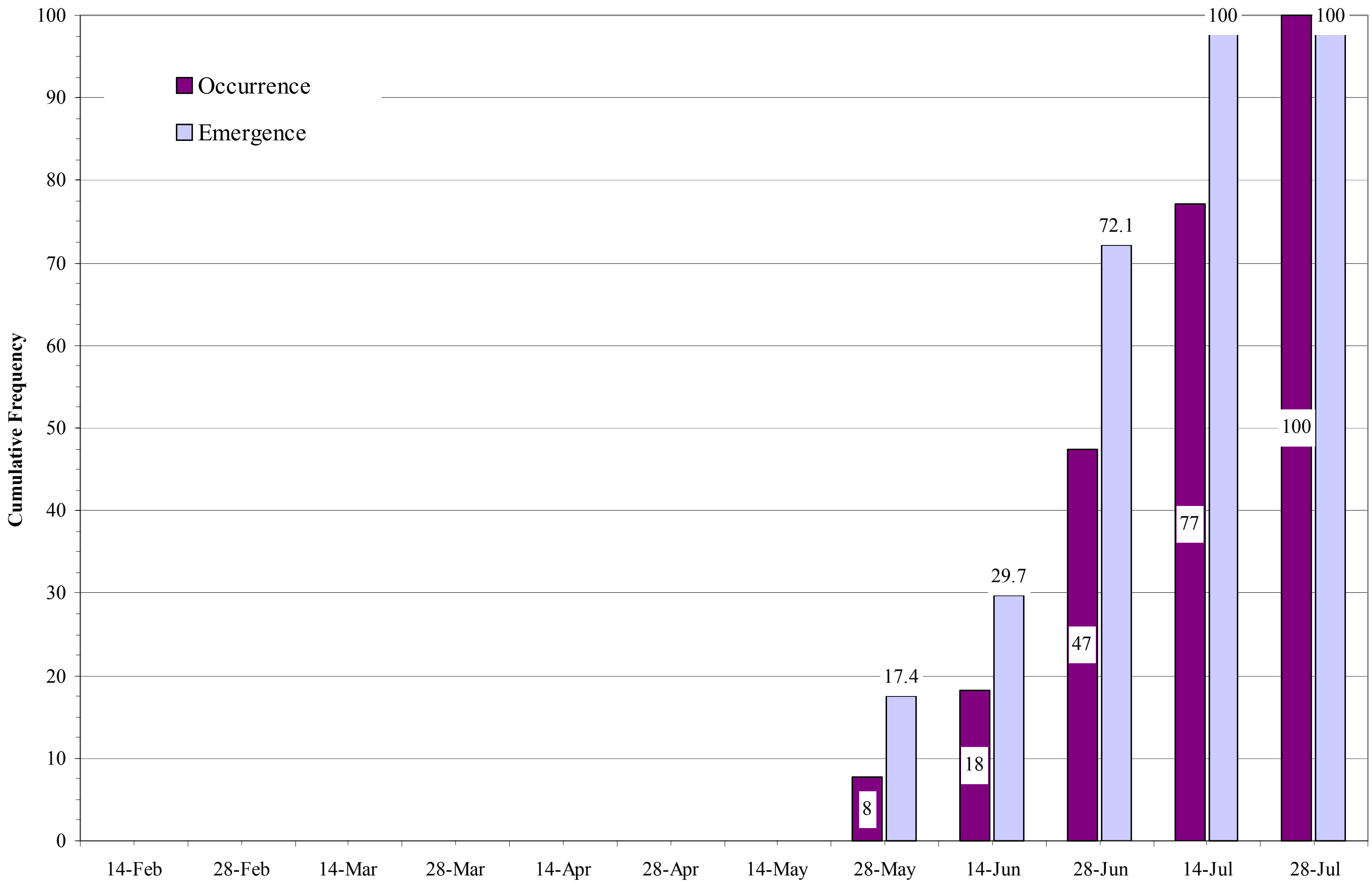

Figure 24. Cumulative age-0 rainbow trout occurrence and emergence frequencies from 22 mainstem and off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

4.2 HABITAT SURVEYS

Four study segments were selected for reach-scale mapping of lateral habitats on the middle Green River (Figure 25; Appendix A). Each study segment was approximately one-mile long, was relatively unconstrained by natural or manmade features, and supported a mixture of mainstem and off-channel habitats. Reach-scale lateral habitat surveys were conducted during 15-16 May 2002 at flows of 2,100 cfs as measured at USGS gage near Auburn (USGS 12113000). Following the initial high flow surveys, discharge in the middle Green River remained higher than average through early July (Figure 26). Because of unusual high flows, the mid-flow lateral habitat surveys were conducted on 1-2 July at a discharge near 1,200 cfs, and low-flow surveys were conducted during 22-23 July 2002 at a discharge of approximately 800 cfs.

4.2.1 Mainstem Habitat

At high flow, low velocity mainstem margin habitat (i.e., velocity <1 fps and width > 1 foot) represented between 22-70% of the mainstem margin length (Table 15; see Appendix A for complete mainstem margin metrics). Study segments 1 and 2, where the river is naturally more confined, had less low velocity mainstem margin habitat at high flows than study segments 3 and 4, which are characterized by a more complex alluvial morphology.

Table 15. Length of low velocity mainstem margin habitat identified in four lateral habitat study segments under three different flow regimes, middle Green River, Washington, 2002.

Study Segment	Location[1]	Extent of Low Velocity Margin		
		High low[2]	Moderate Flow[3]	Low Flow[4]
1	RM 58.5 to RM 59.5	33%	36%	100%
2	RM 44.6 to RM 43.8	22%	37%	43%
3	RM 40 to RM 39	64%	61%	80%
4	RM 36.2 to RM 35	69%	74%	90%

[1] Approximate location in river miles based on Williams et al. 1975

[2] High flow surveys conducted at 2,100 cfs (study segments 3 and 4) and 1,820 cfs (study segments 1 and 2) as measured at the Green River near Auburn USGS gage.

[3] Moderate flow surveys conducted at 1,220 cfs (study segments 3 and 4) and 1,190 cfs (study segments 1 and 2) as measured at the Green River near Auburn USGS gage.

[4] Low flow surveys conducted at 808 cfs (study segments 3 and 4) and 696 cfs (study segments 1 and 2) as measured at the Green River near Auburn USGS gage.

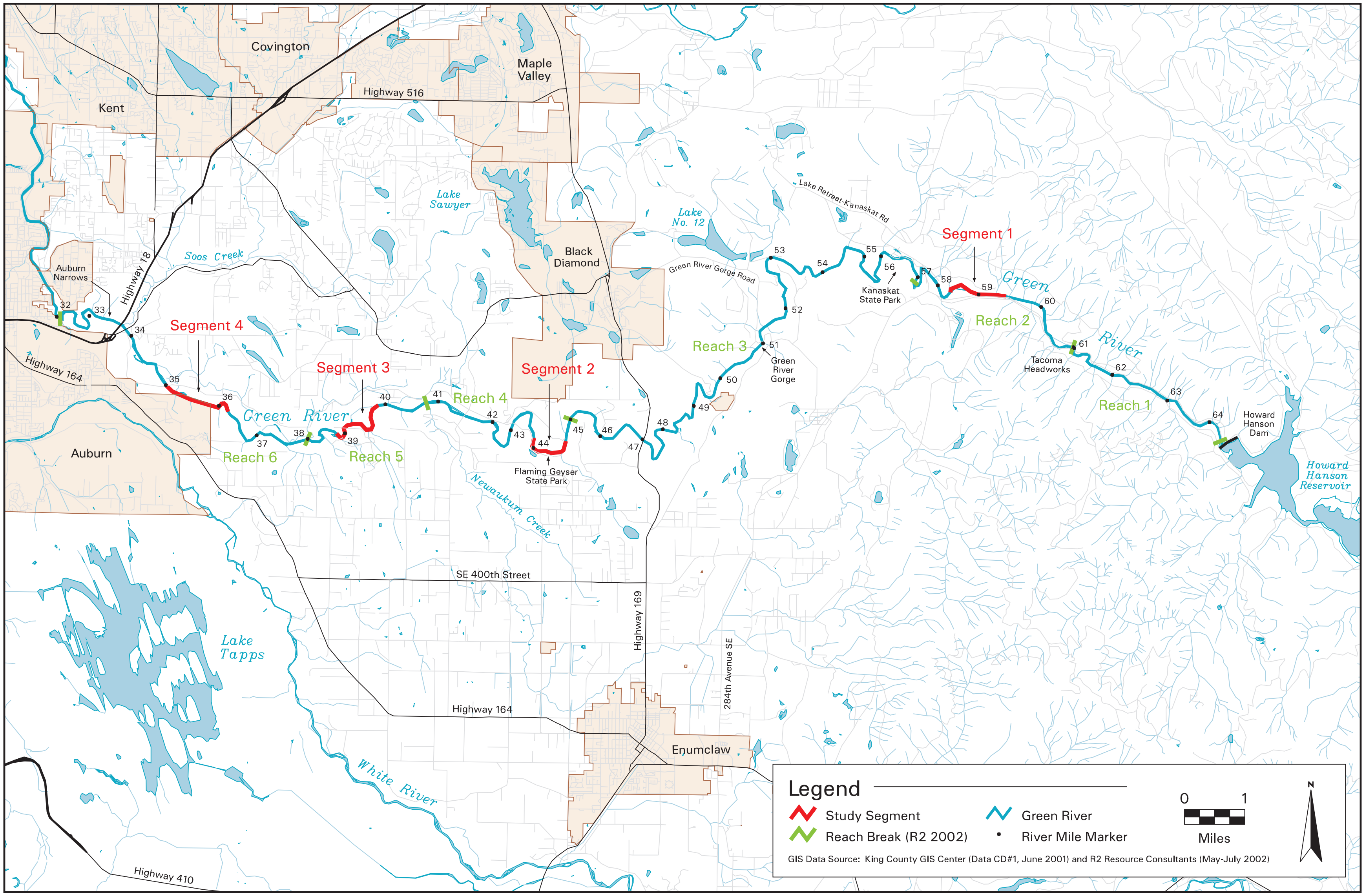

Figure 25. Location of reach-scale lateral habitat study segments in the middle Green River, Washington, 2002.

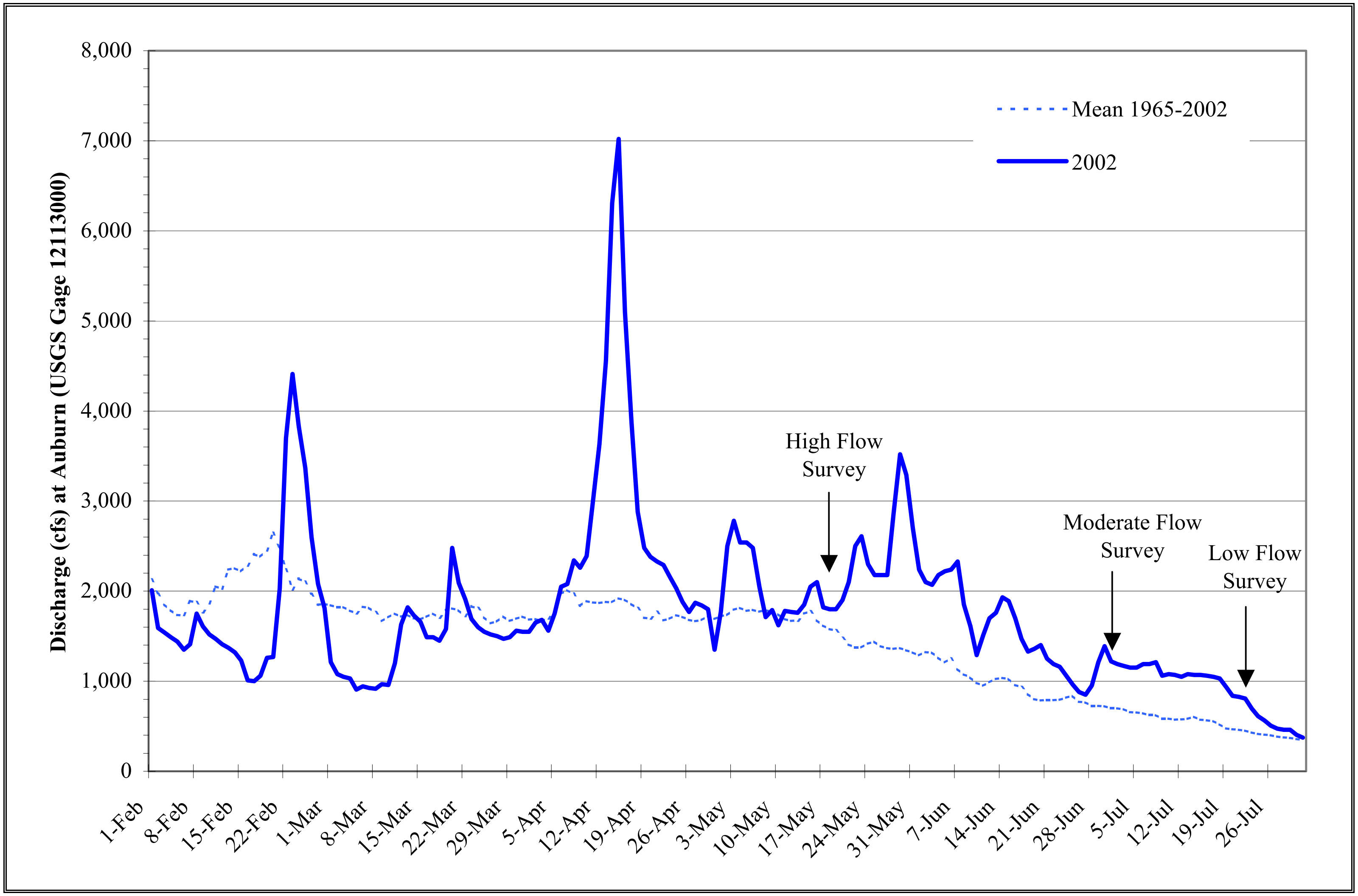

Figure 26. Discharge (cfs) as measured at USGS Gage 121113000, middle Green River, Auburn, Washington.

During the high flow regime, low velocity mainstem margin habitat in all study segments, except segment 3, consisted primarily of narrow bands (i.e., 1-5 ft wide) adjacent to relatively steep (>4% slope) vegetated banks (Figures 27 through 30). Low velocity habitat along steep margins formed in association with inundated or overhanging vegetation and woody debris. Even where overall water velocities were in excess of 1 fps immediately adjacent to the bank, small pockets of lateral habitat were observed around woody debris features. In study segment 3, the presence of extensive gravel bars results in the greater extent of gently sloping, unvegetated bar margins when compared to the other study segments (Figure 29). Slough or backwater habitats were also common at the downstream ends of gravel bars in study segment 3. However, except for sloughs, mainstem margin habitats also consisted predominantly of narrow banks (1-5 feet wide) in study segment 3 under the high flows.

The lineal length of low velocity mainstem margin habitat increased as flows dropped (Table 16). At moderate flows, mainstem margin habitat units in most reaches remained narrow and continued to be influenced by inundated or overhanging vegetation and small woody debris. Wider lateral habitat units and simple, unvegetated margins were most common in study segments 3 and 4, where extensive transverse and point gravel bars are present (Figures 27 through 30). Unvegetated margins represented approximately 24% of the total mainstem margin length in study segments 3 and 4 at moderate flows, compared to between 10-20% at higher discharge levels.

Low velocity mainstem margin habitat in the middle Green River is greatest at lower flows (Table 16). However, at flows of around 700-800 cfs, mainstem margin habitat units are frequently disconnected from cover provided by vegetation or woody debris. Mainstem margin substrates in study segment 1 consist primarily of boulder and cobble size substrate, thus all mainstem margins in this reach provided at least a 1 ft-wide seam of low velocity habitat under the low flow regime (800 cfs at Auburn; 465 cfs at Palmer). However, more than 75% of the marginal habitat in study segment 1 consisted of unvegetated banks that provided little overhead cover (Figure 27). Much of the mainstem margin area in study segment 2 continued to contain water velocities in excess of 1 fps, even at low flows (Figure 28). Mainstem margin habitat in Segment 2 continued to be influenced by overhanging vegetation and woody debris, however (<20 percent of total length classified as unvegetated). In study segments 3 and 4, more than 80% of the total mainstem margin provided at least some low velocity habitat under the low flow regime, although, at least 50% of those areas lacked vegetation or complexity provided by woody debris (Figures 29 and 30; see Appendix A for additional mainstem margin metrics).

Table 16. Length of wetted side channel habitat identified in lateral habitat study segments under three different flow regimes, middle Green River, Washington, 2002.

Study Segment	Predominant Water Source[1]	Length of Wetted Side Channel		
		High Flow[2]	Moderate Flow[2]	Low Flow[4]
1	Surface Inflow	1,811 ft	1,474 ft	1,337 ft
	Groundwater	425 ft	425 ft	425 ft
2	Surface Inflow	4,319 ft	1,760 ft	1,326 ft
	Groundwater	0 ft	2,480 ft	2,449 ft
3	Surface Inflow	7,713 ft	6,339 ft	6,395 ft
	Groundwater	0 ft	842 ft	677 ft
4	Surface Inflow	1,258 ft	713 ft	713 ft
	Groundwater	1,054 ft	0 ft	0 ft

[1] Surface inflow includes mainstem flow or tributary inflow; groundwater includes hyporheic flow of contributions from floodplain wetlands.

[2] High flow surveys conducted at 2,100 cfs (study segments 3 and 4) and 1,820 cfs (study segments 1 and 2) as measured at the Green River near Auburn USGS gage.

[3] Moderate flow surveys conducted at 1,220 cfs (study segments 3 and 4) and 1,190 cfs (study segments 1 and 2) as measured at the Green River near Auburn USGS gage.

[4] Low flow surveys conducted at 808 cfs (study segments 3 and 4) and 696 cfs (study segments 1 and 2) as measured at the Green River near Auburn USGS gage.

Sloughs or backwater features located within the bankfull channel and maintaining a direct connection with the mainstem at all flows were also enumerated as mainstem margin habitats. Sloughs and backwaters tended to be located at the downstream ends of gravel bars or near side channel outlets. Sloughs represented a very small proportion of the total length of mainstem margin habitat in study segments 1, 2, and 4 (<5%), but tended to be wider in area than other mainstem margin habitat units (Figures 27 through 30). Sloughs were most common in study segment 3 (up to 20%). The length of slough/backwater habitat decreased with discharge in all study segments, except study segment 3, where the inverse occurred (Figure 29).

Gravel bar pools were infrequent occurrences in all study segments. Study segments 3 and 4 contained small quantities (<1% total length) of gravel bar pool mainstem margin habitat under the moderate and low flow regimes (Figures 29 and 30), while the other study segments were devoid of this habitat feature (Figures 27 and 28).

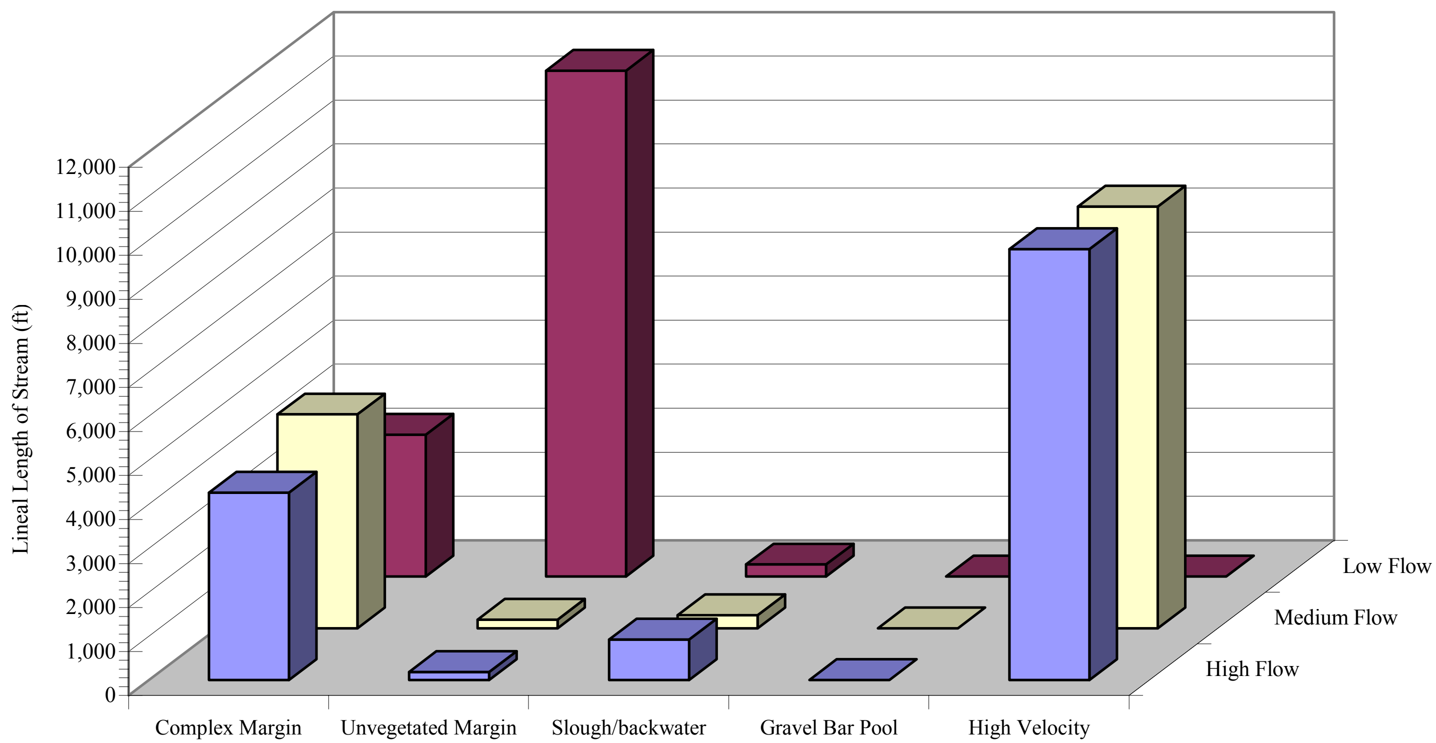

Figure 27. Mainstem margin juvenile salmonid habitat available in study segment 1 under three different flow regimes, middle Green River, 2002.

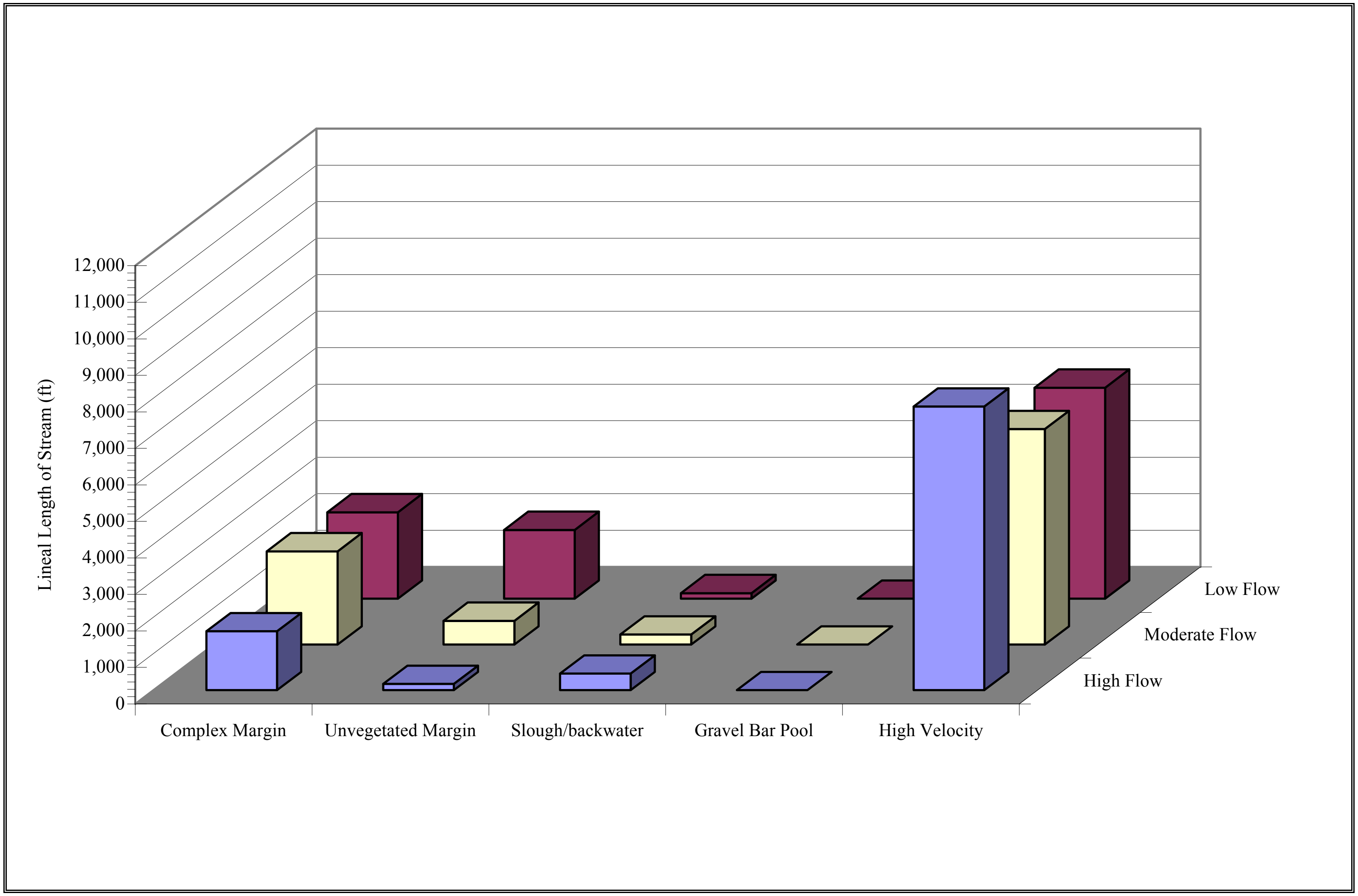

Figure 28. Mainstem margin juvenile salmonid habitat available in study segment 2 under three different flow regimes, middle Green River, 2002.

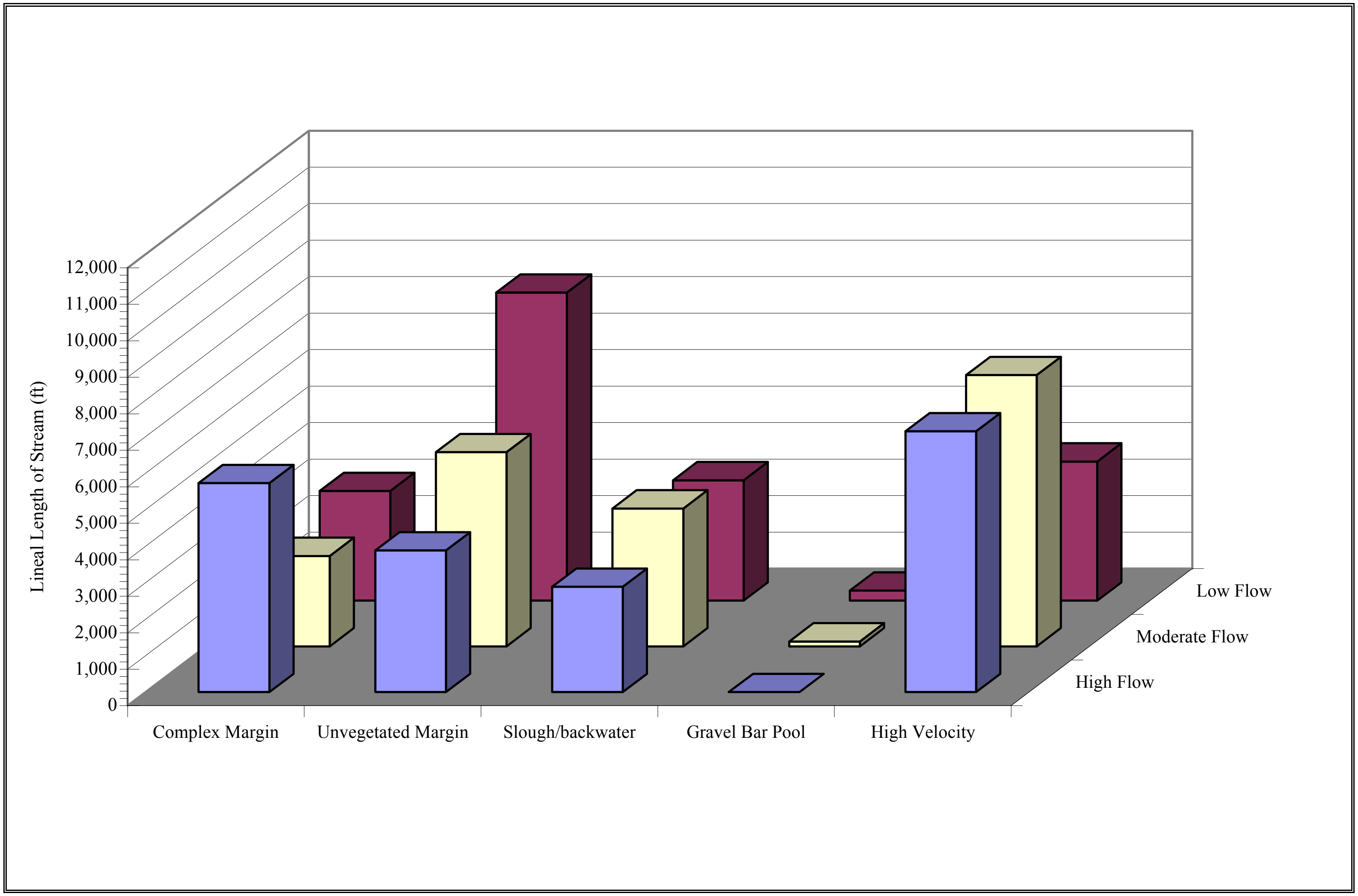

Figure 29. Mainstem margin juvenile salmonid habitat available in study segment 3 under three different flow regimes, middle Green River, 2002.

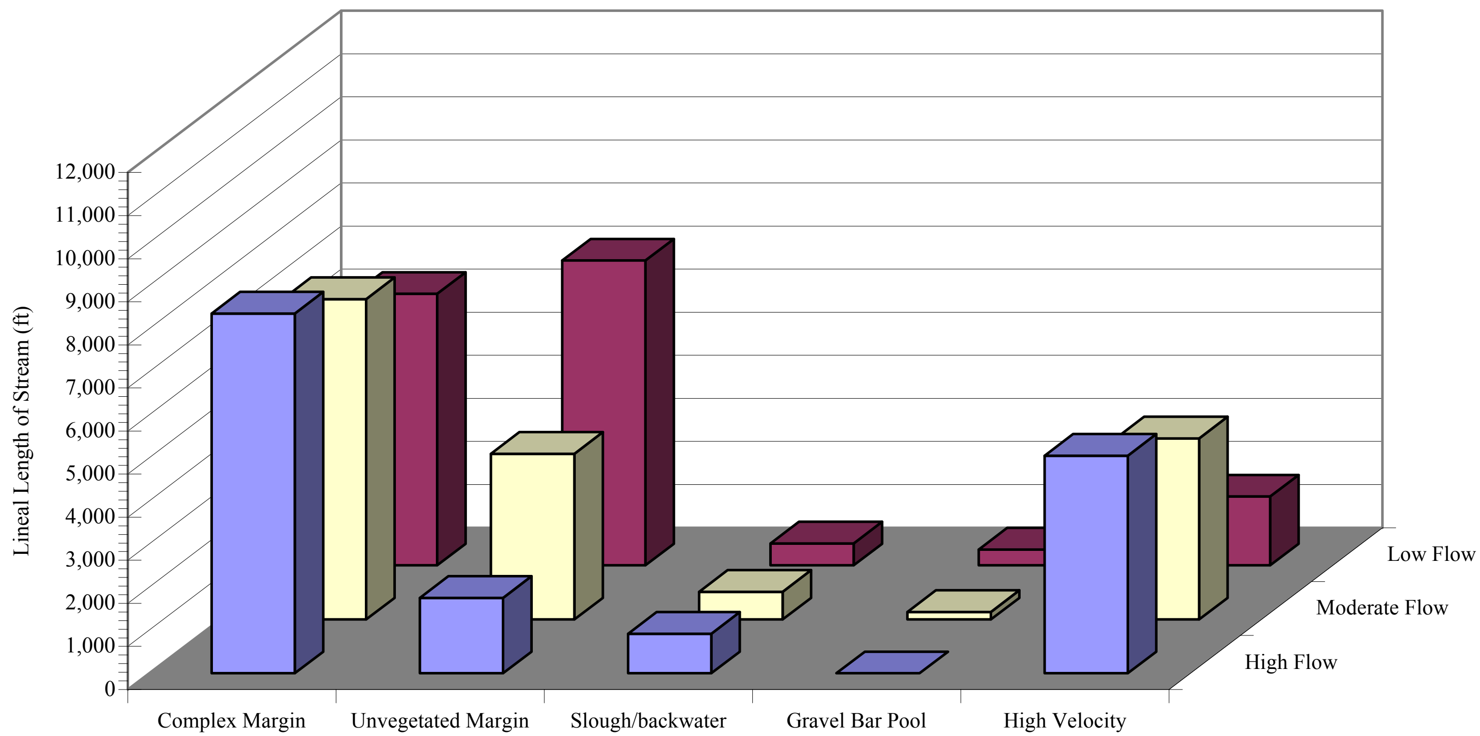

Figure 30. Mainstem margin juvenile salmonid habitat available in study segment 4 under three different flow regimes, middle Green River, 2002.

4.2.2 Off-Channel Habitat

Active side channels (i.e., backbar, abandoned, and wallbase) were the predominant off-channel habitat type identified during the lateral habitat survey conducted on the middle Green River (see Appendix A for complete side channel metrics). A total of 15 different active side channels (i.e., channels connected to the mainstem Green River during typical springtime flows) and one beaver pond complex were identified in the four lateral habitat study segments in the middle Green River (Figures A-1 through A-12). Several transient overflow paths also appeared during flows in excess of 2,100 cfs at the Auburn USGS gage. Connectivity in active side channels was maintained by a variety of water sources; however, each side channel classified as active was observed to transmit surface flow from the mainstem at discharge of 2,100 cfs as measured at the Auburn gage.

A total of approximately 14,700 lineal feet of off-channel habitats was identified in the four study segments of the middle Green River (Figure 31). Study segment 3 contained more than 50% (7,708 ft) of the total side channel lineal length. Length of side channel habitat decreased as the discharge in the middle Green River decreased (Figure 31). Approximately 70% of side channel habitat was present at moderate flows, while 60% remained under low flow conditions (Figure 32). Side channels ranged from approximately 3 ft wide to over 70 ft in width. At high flow, larger side channels transmitted substantial (> 50%) quantities of the total flow (e.g., RB39.8 in study segment 3). As flows receded, surface inflows to some side channels decreased or ceased altogether (Table 16). In some cases, side channel connectivity was maintained at the side channel outlet by groundwater, while in other cases, side channel habitats in the middle Green River were supplemented from lateral hyporheic flow from the mainstem (see Appendix for additional side channel metrics).

A total of more than 412,000 ft^2 of wetted side channel habitat area was identified under the high flow regime (Figure 31). Like wetted lineal length, off-channel wetted area was largest in study segment 3, comprising more than 68% of the total off-channel area present under the high flow regime (Figure 33; Appendix A). Total wetted off-channel habitat area under the moderate (342,923 ft^2) and low (291,204 ft^2) flows were reduced by approximately 17% and 30%, respectively (Figure 33).

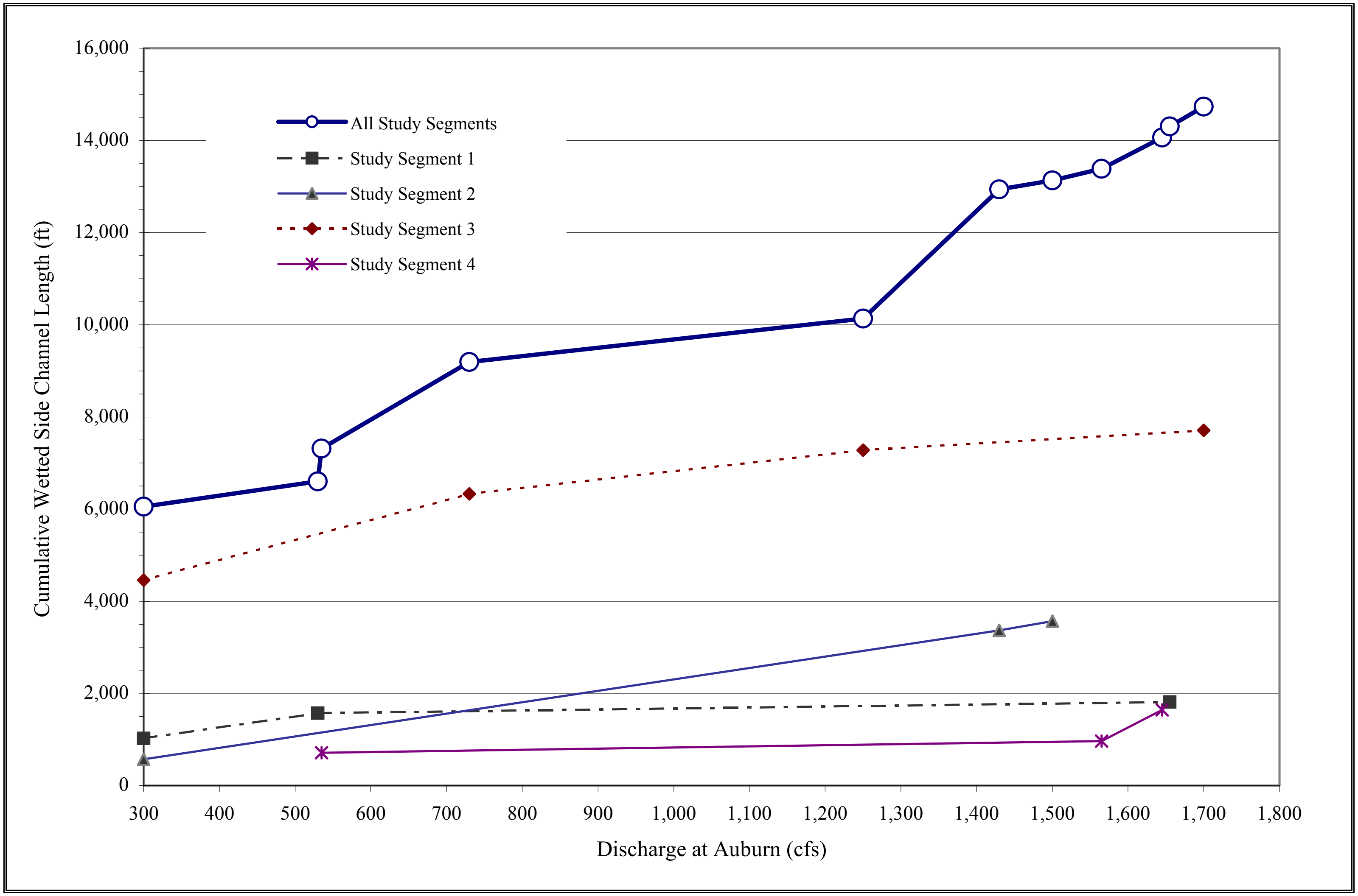

Figure 31. Cumulative wetted side channel length in four study segments under three different flow regimes, middle Green River, Washington, 2002.

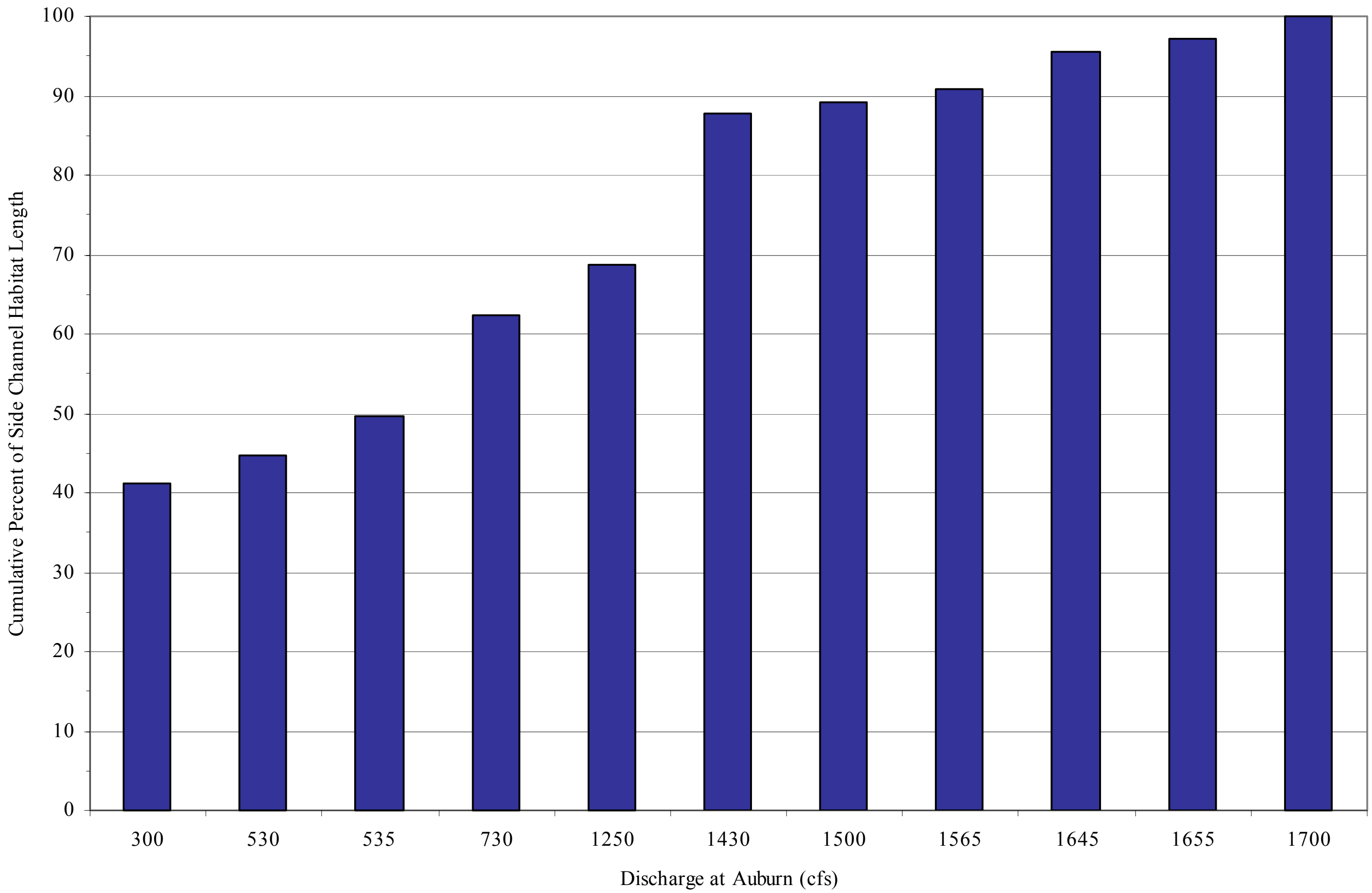

Figure 32. Cumulative percent of wetted side channel length in four study segments, middle Green River, Washington, 2002.

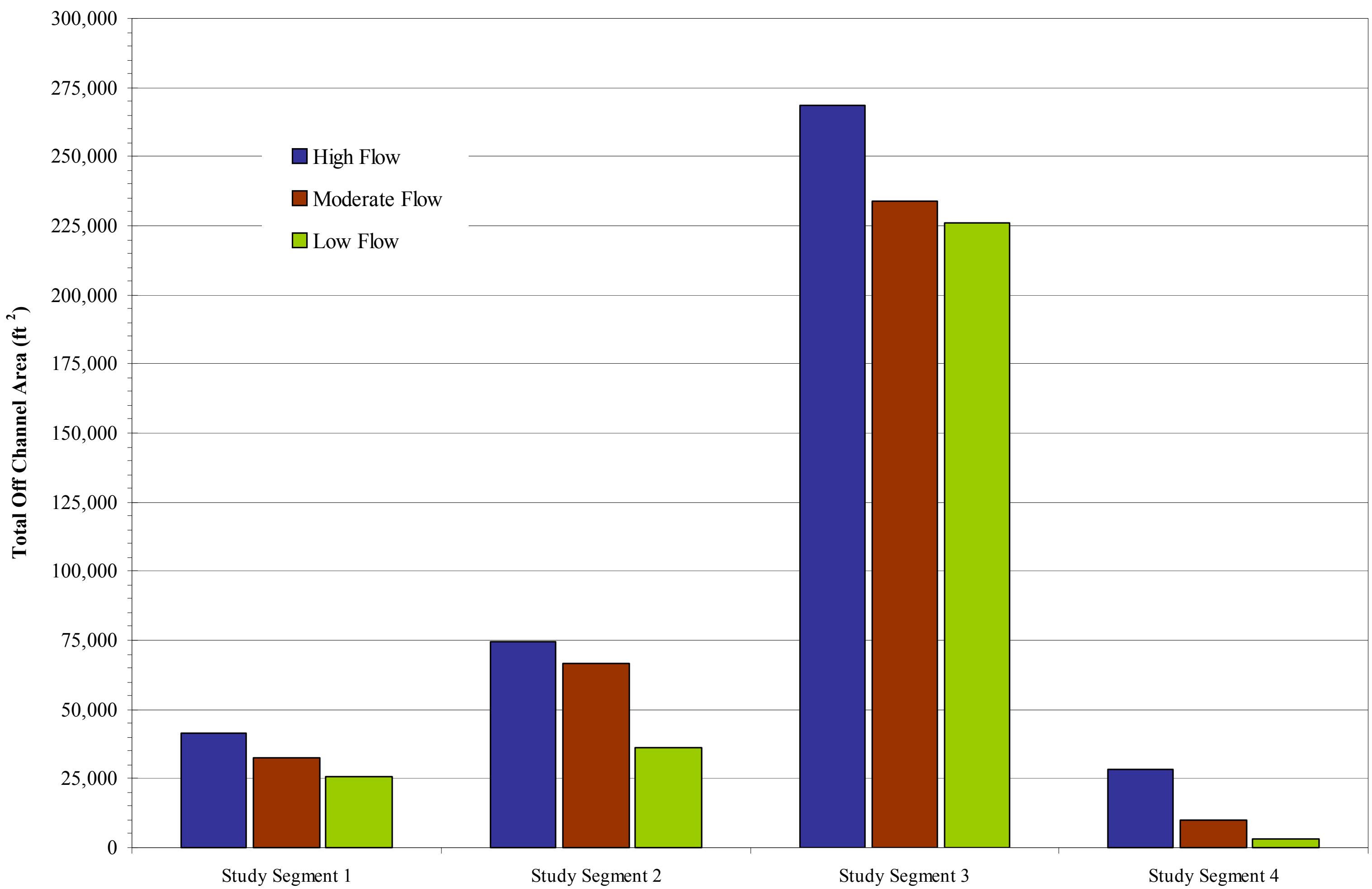

Figure 33. Total wetted side channel area (ft^2) in four study segments under three different flow regimes, middle Green River, Washington, 2002.

5. DISCUSSION

Extensive modifications of watersheds for municipal water supply, hydroelectric production, flood control, irrigation, navigation, and other diversions have permanently changed the physical and integrity of many Pacific Northwest river systems (Wissmar and Bisson 2003). The recent listing of various stocks of Pacific salmon under the Endangered Species Act has focused the national attention on the conditions of rivers and streams in the Puget Sound advancing river restoration and ecosystem function. Restoration as defined by the National Research Council (1992) is the reestablishment of the structure and function of an ecosystem, including its natural integrity. Restoration of ecosystem structure should provide a healthy and functioning watershed and riverine system (Williams et al. 1997). Attempts to restore river habitat and function using large woody debris (Dominguez and Cederholm 2000) and sediment nourishment (USFWS and Hoopa Valley Tribe 1999) already appear to have been successful in support of Pacific Salmon.

The role of habitat selection among juvenile salmonids has been widely studied in the Puget Sound Region as well as over the Pacific Northwest since the listing of Chinook salmon and other species under ESA (Quinn 2005). Juvenile salmonids in the middle Green River utilize the same suite of habitats that other studies have identified as key to their life history strategies. The main focus of this study was to obtain site-specific information from the middle Green River on the periodicity, abundance, and habitat use of juvenile Chinook, coho, and chum salmon, and rainbow trout over a broad period of time so that resource managers can make informed decisions during the water management of Howard Hanson Dam.

Juvenile salmonids in the middle Green River display discrete and separate life history components. Juvenile Chinook salmon are the first to emerge in the middle Green River, followed shortly by chum and then coho salmon, while rainbow trout are the latest emerging species. Emergence timing was also discrete within the species whereby juvenile Chinook, coho, and chum emergence was 7-14 days later in upriver sites compared to the majority of the monitoring sites located downstream from Flaming Geyser State Park. The difference in emergence timing between upstream and downstream locations in salmon was not apparent for rainbow trout, however.

We observed significant differences in habitat use of juvenile salmonids upon their emergence; the common thread amongst the species was the heavy reliance on mainstem margin habitat immediately after their emergence. Juvenile Chinook salmon and rainbow trout did not utilize off-channel habitat in the same proportion that chum and coho salmon utilize these habitats in the middle Green River. Juvenile Chinook abundance was significantly greater in mainstem habitats, indicating their preference for these lateral habitats during their residence in the middle Green River. Off-channel habitats provide a key function for juvenile salmonids in the middle Green River. Juvenile coho salmon growth was significantly greater in these habitats compared to off-channel site.

We observed significant differences between mean water temperatures monitored throughout the study period in regions of the river (i.e., upstream and downstream locations (Mann Whitney Rank Sum Test; $T = 18654$; $P < 0.0001$), as well as from mainstem and off-channel habitats (Mann Whitney Rank Sum Test; $T = 23345$; $P < 0.0067$) (Figure 34). Off-channel habitats generally provided warmer temperatures early in the season that promoted the growth of juvenile salmonids and decreased the daily fluctuations of water temperature as well as providing for overall cooler water temperatures later in the season (Figure 34). The importance of size in juvenile salmonids is inferred to give them a competitive advantage in overwinter survival (see review in Quinn 2005).

The availability of low velocity mainstem margin habitats in the middle Green River is affected by mainstem flow level as well as physical characteristics including channel type (i.e., semi-alluvial, meandering, braided), woody debris, sediment accumulation or scour, bank configuration, and riparian vegetation. Semi-alluvial channels such as study segments 1 and 2, with coarse substrate and few mobile gravel bars, have steep, vegetated banks and side channels that are relatively fixed in terms of their location and configuration. As a result, lateral habitat availability in this type of channel is primarily dependent on flow level; high flows reduce the availability of mainstem margin habitat but increase the area of wetted side channels. Low flows increase mainstem margin habitat availability, but disconnect that habitat from overhead cover and reduce the amount of wetted side channel habitat. The addition of woody debris and gravel under the AWSP should increase the number of gravel bars and deposits of large and small woody debris along the channel margins in these segments, augmenting both the amount and diversity of lateral habitats available to juvenile salmonids.

In contrast, braided alluvial channels such as study segments downstream from Flaming Geyser State Park currently offer a diverse array of mainstem and off-channel habitat types. Processes that form and maintain the diverse assemblage of lateral habitats are not expected to change as a result of the AWSP (although implementation of the gravel and woody debris may be important to ensure those processes remain functional). The location and connectivity of mainstem margin habitat types will continue to change over time in these channel segments as a result of both natural channel processes (e.g., the current shifting of mainstem flow away from the existing channel and into RBSC39.8) as well as potentially through management action implemented under the AWSP or other habitat restoration programs.

Baseline information on reach-scale lateral habitat availability and connectivity can be used to guide flow management under the AWSP. Reach-scale lateral habitat maps can be used to link the result of biological monitoring to the availability of important habitats both spatially (i.e., throughout the reach) and temporally (as flows change over the season). This information can be used to guide flow management decisions. For example, it may be possible to maximize the extent or connectivity of specific mainstem or off-channel habitat types that biological monitoring shows to be most important for certain species or life history strategies during a given time period. In addition, reach-scale monitoring will document changes in the pattern of habitat availability over time. Information on existing reach scale lateral habitat availability may be used to identify areas where specific high quality habitat types are rare or absent, allowing restoration efforts to focus on creating those features. Long-term monitoring of lateral habitats will illustrate the effectiveness of specific habitat restoration actions, and can be used to adapt future management actions accordingly.

Restoration activities under way in the Green River should not overlook the importance of mainstem margin habitat as well as off-channel habitat during restoration planning activities. Information collected during this study from recent restoration sites in the middle Green River (e.g., Porter Levee suggests that various species and life stages of salmonids will utilize restoration zones in the Green River to a level at least on par with pre-existing off-channel habitats. Future monitoring efforts should attempt to tease out the level of increased production that may be attributed to restoration processes. In an effort to show ecosystem response, biological monitoring could be extended to macroinvertebrates as well as fish species other than salmonids (Kauffman et al. 1997). However, construction of restoration projects is not the only option that should be analyzed during restoration/enhancement activities. The middle Green River beginning at Flaming Geyser State Park and continuing downstream to Highway 18 is one of the few remaining stretches of river in the Greater Puget Sound Region that has not been completely disconnected from its off-channel habitats; however these habitats are encroached upon on an annual basis. Restoration and enhancement measures should also strive to purchase or obtain conservation easements on middle Green River lands as they become available (i.e., Metzler and O'Grady Parks).

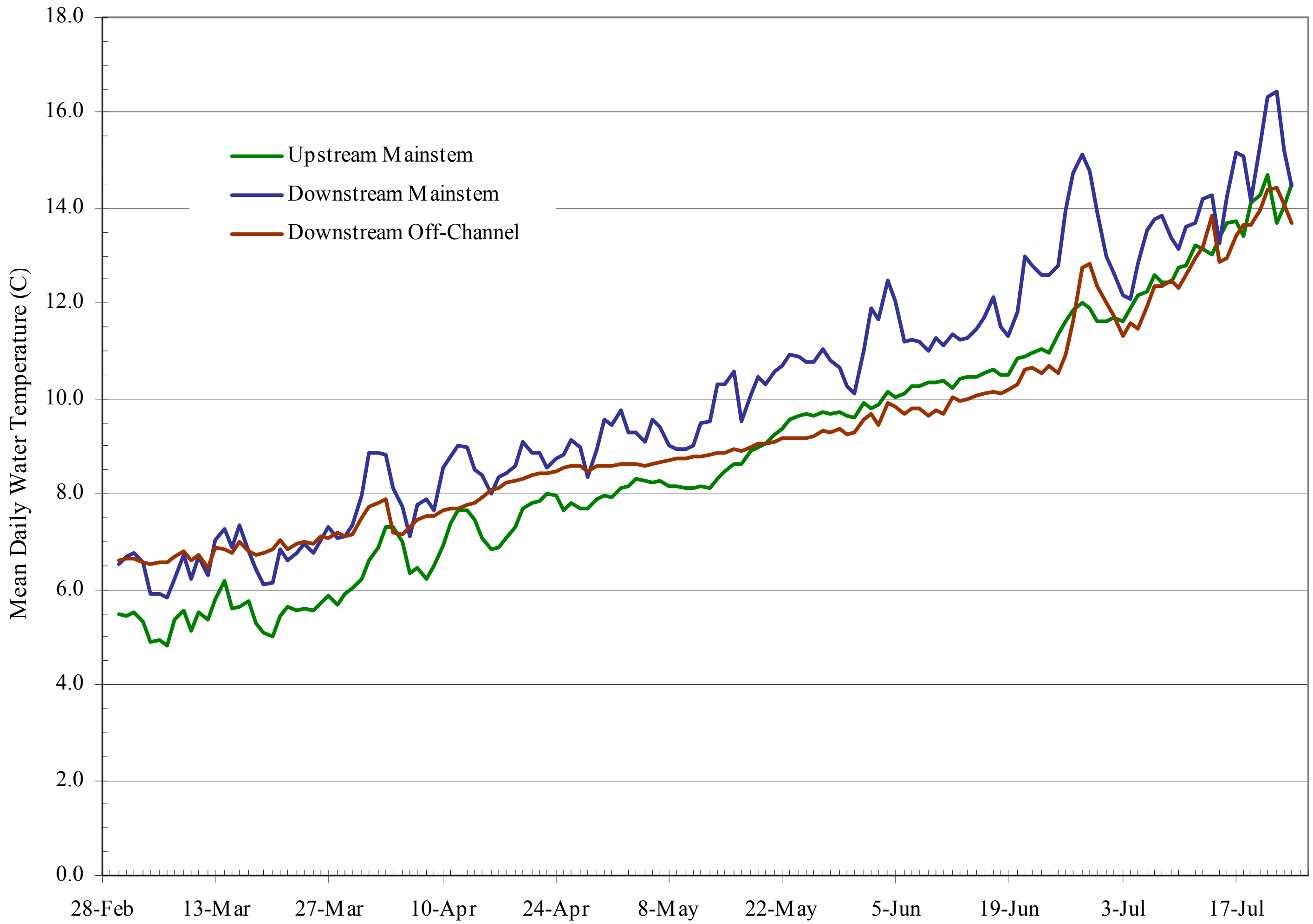

Figure 34. Mean daily water temperatures from upstream and downstream mainstem, and downstream off-channel study sites located in the middle Green River, King County, Washington, 1998-2002.

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APPENDIX A

Study Segment Data

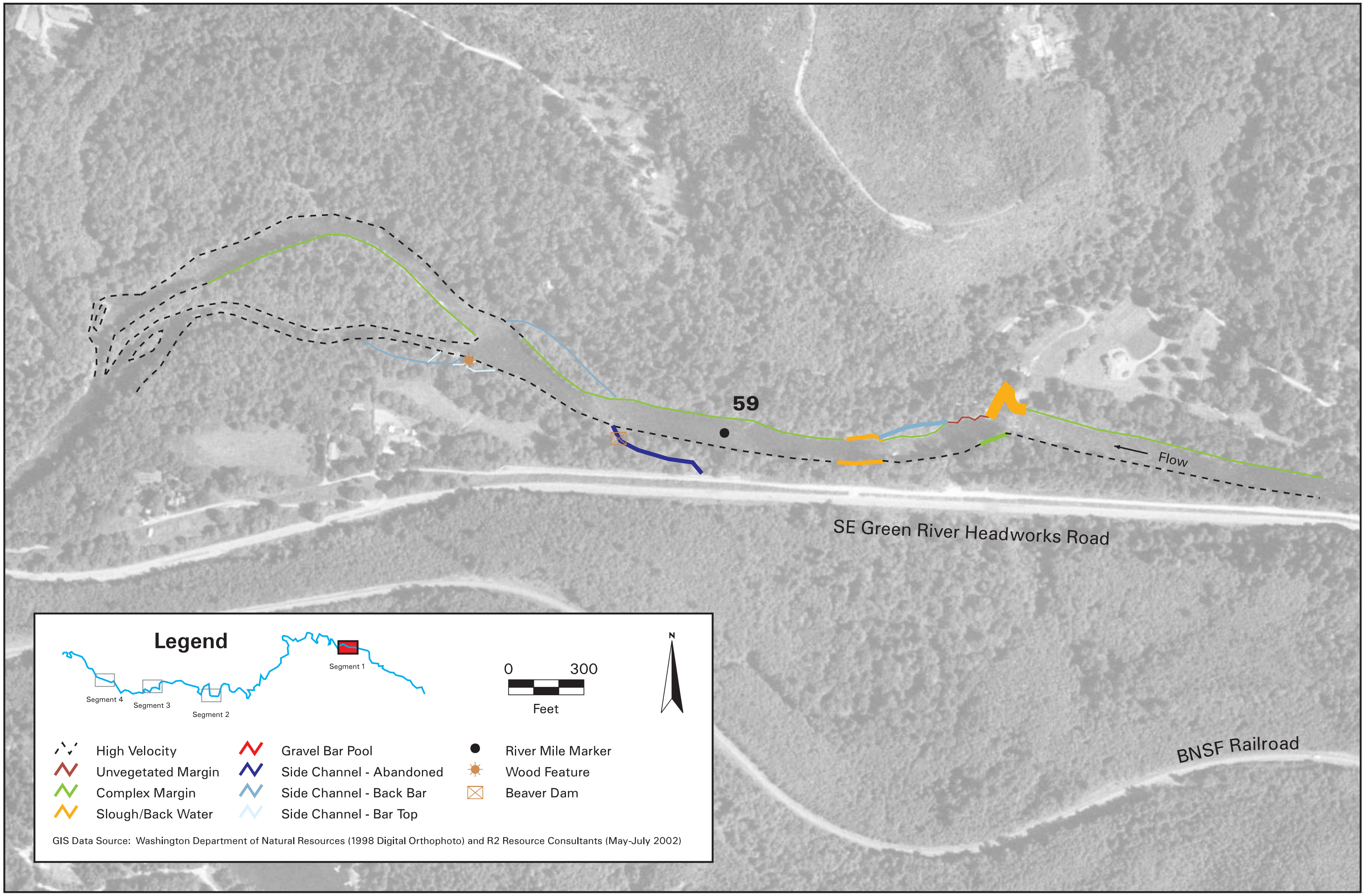

Figure A−1. Lateral habitat study segment 1 under high flow regime (2,100 cfs), middle Green River, Washington, 2002.

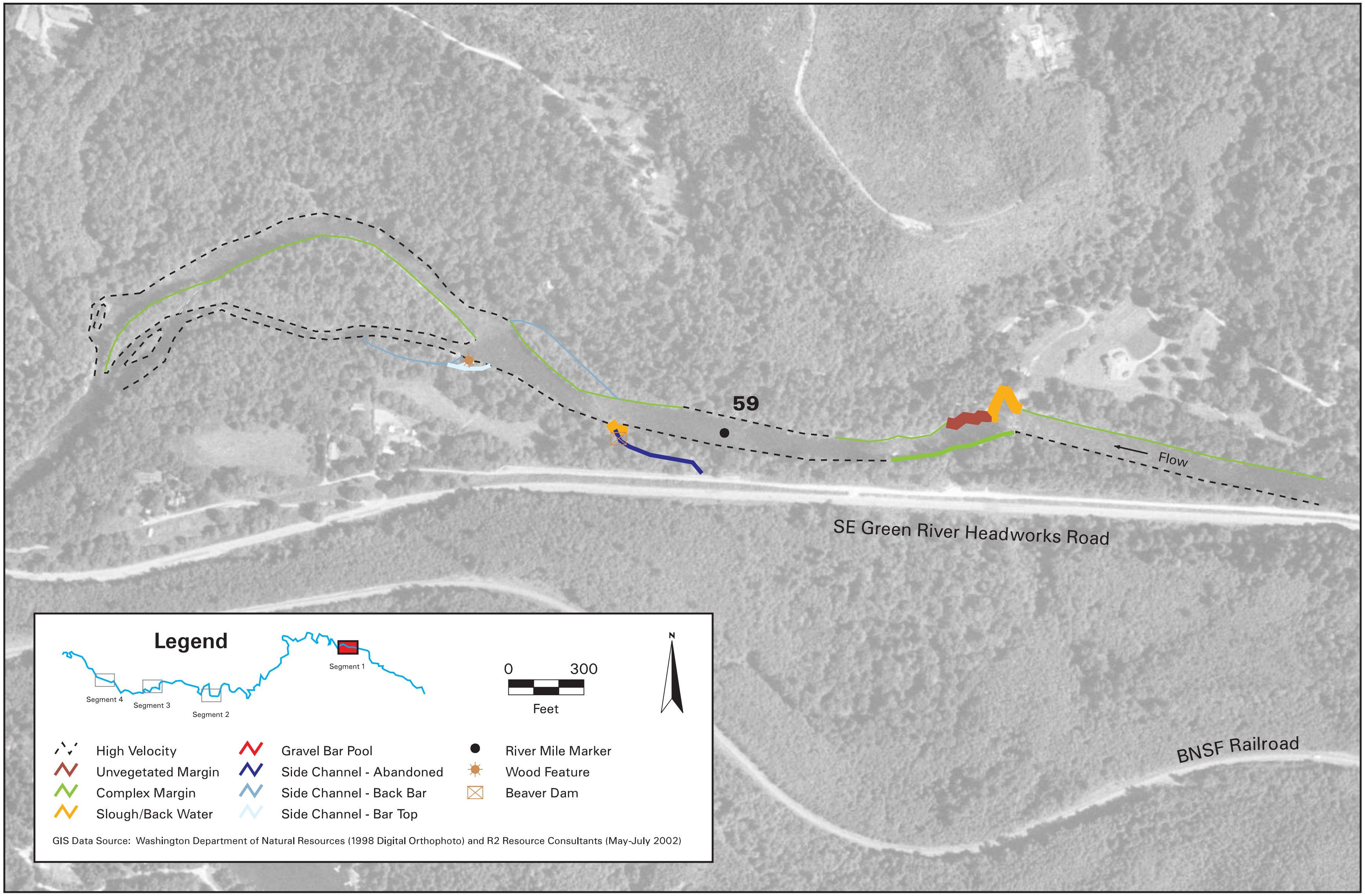

Figure A−2. Lateral habitat study segment 1 under moderate flow regime (1,200 cfs), middle Green River, Washington, 2002.

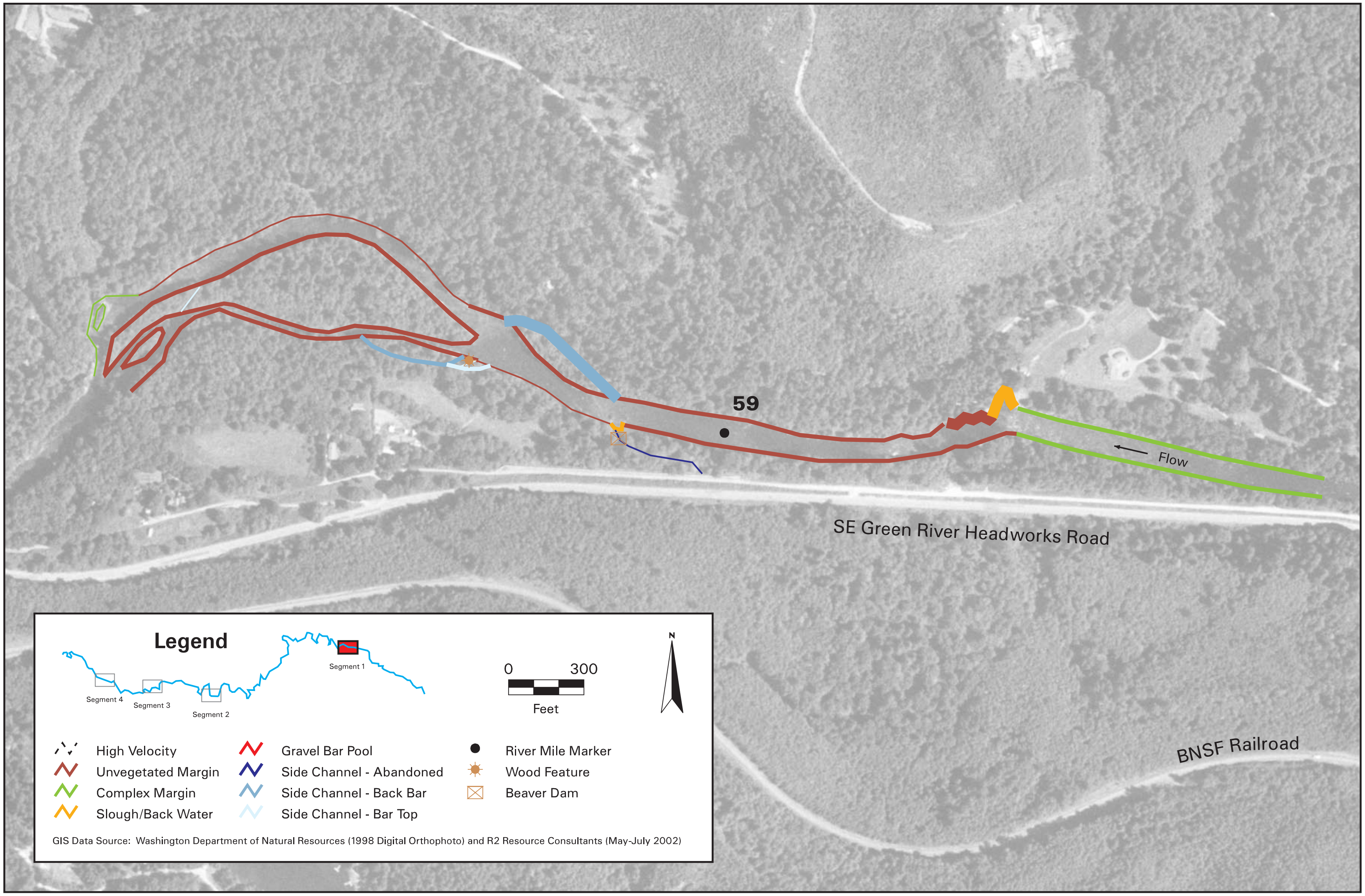

Figure A−3. Lateral habitat study segment 1 under low flow regime (800 cfs), middle Green River, Washington, 2002.

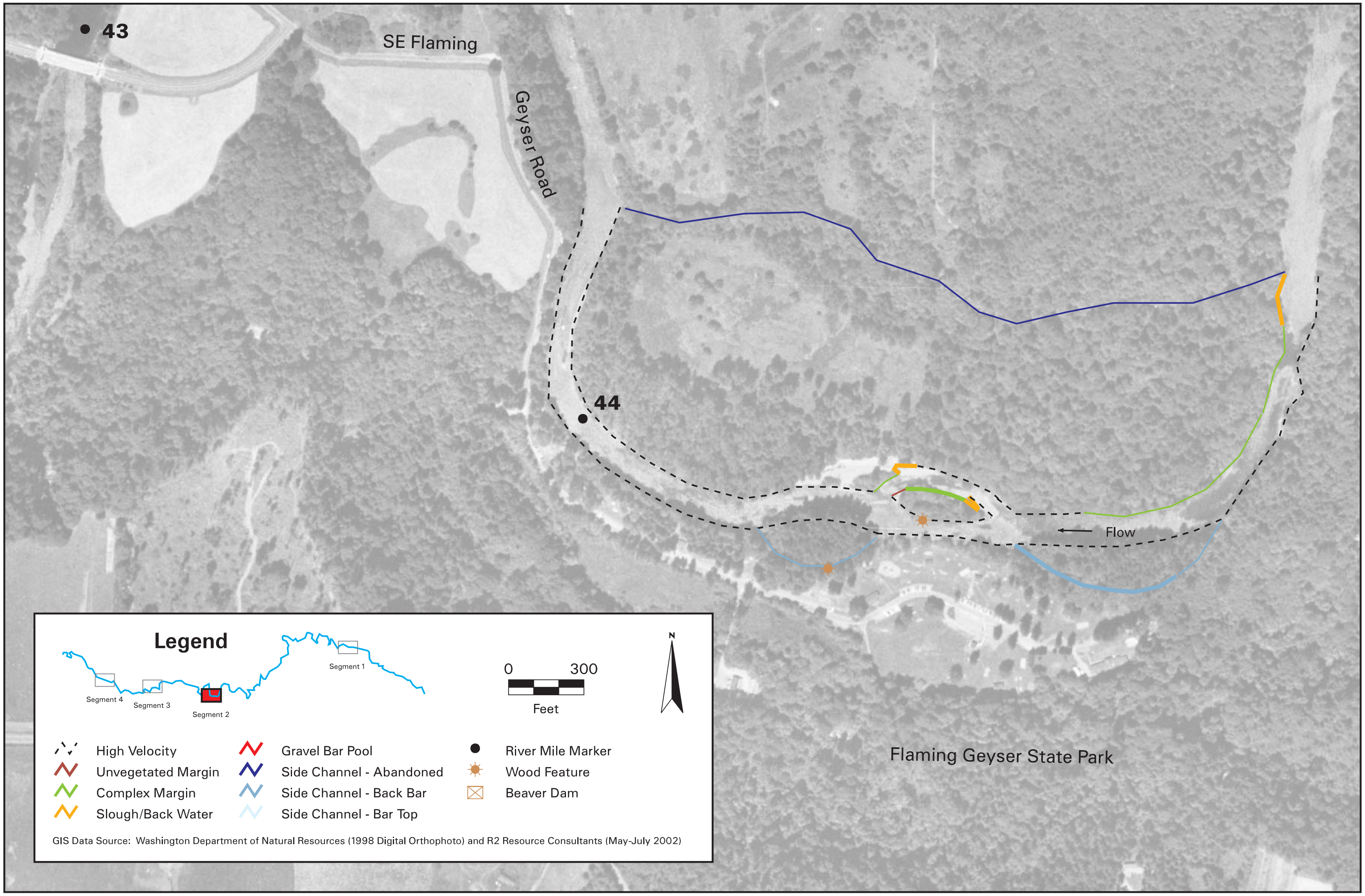

Figure A−4. Lateral habitat study segment 2 under high flow regime (2,100 cfs), middle Green River, Washington, 2002.

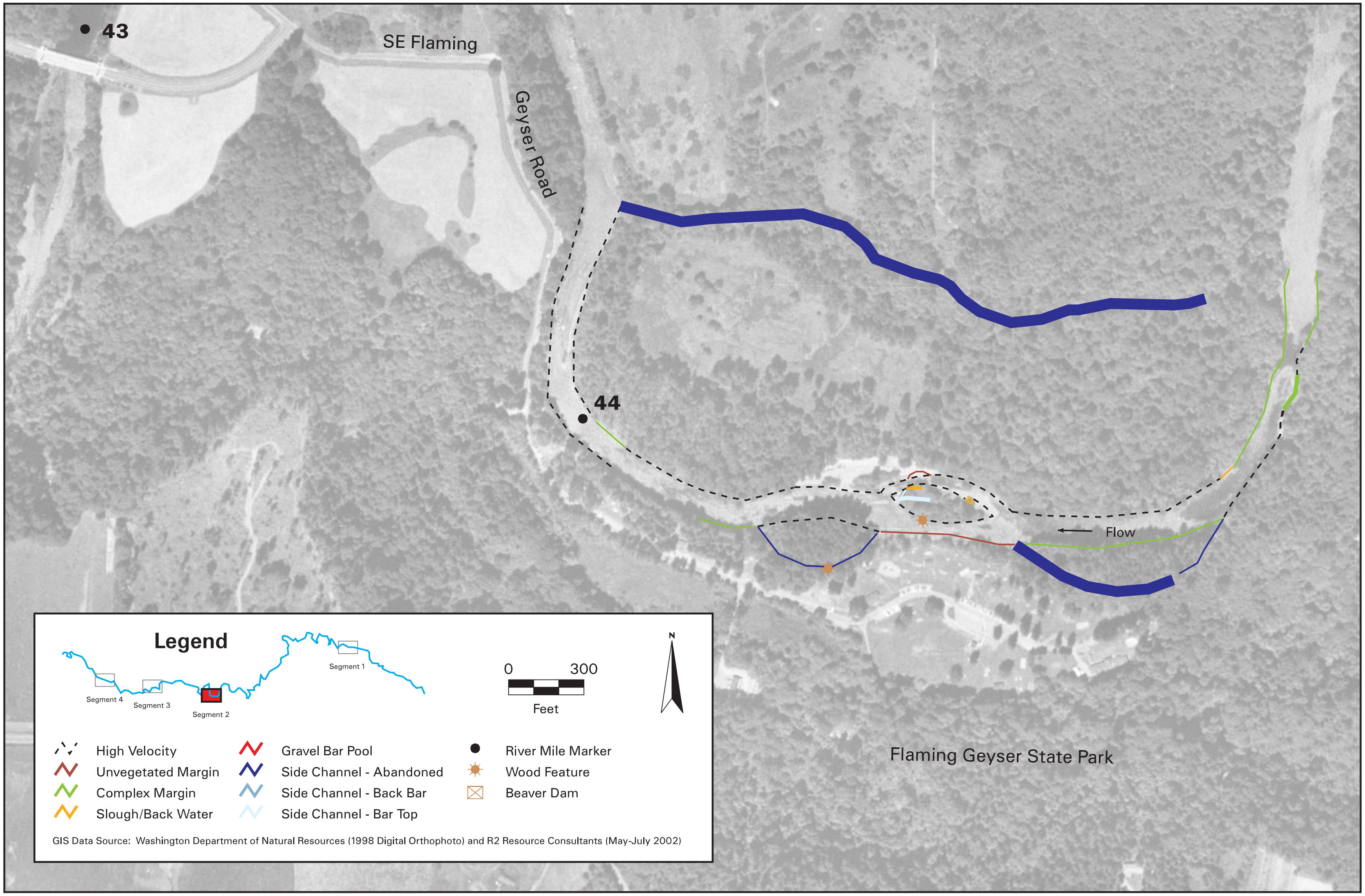

Figure A−5. Lateral habitat study segment 2 under moderate flow regime (1,200 cfs), middle Green River, Washington, 2002.

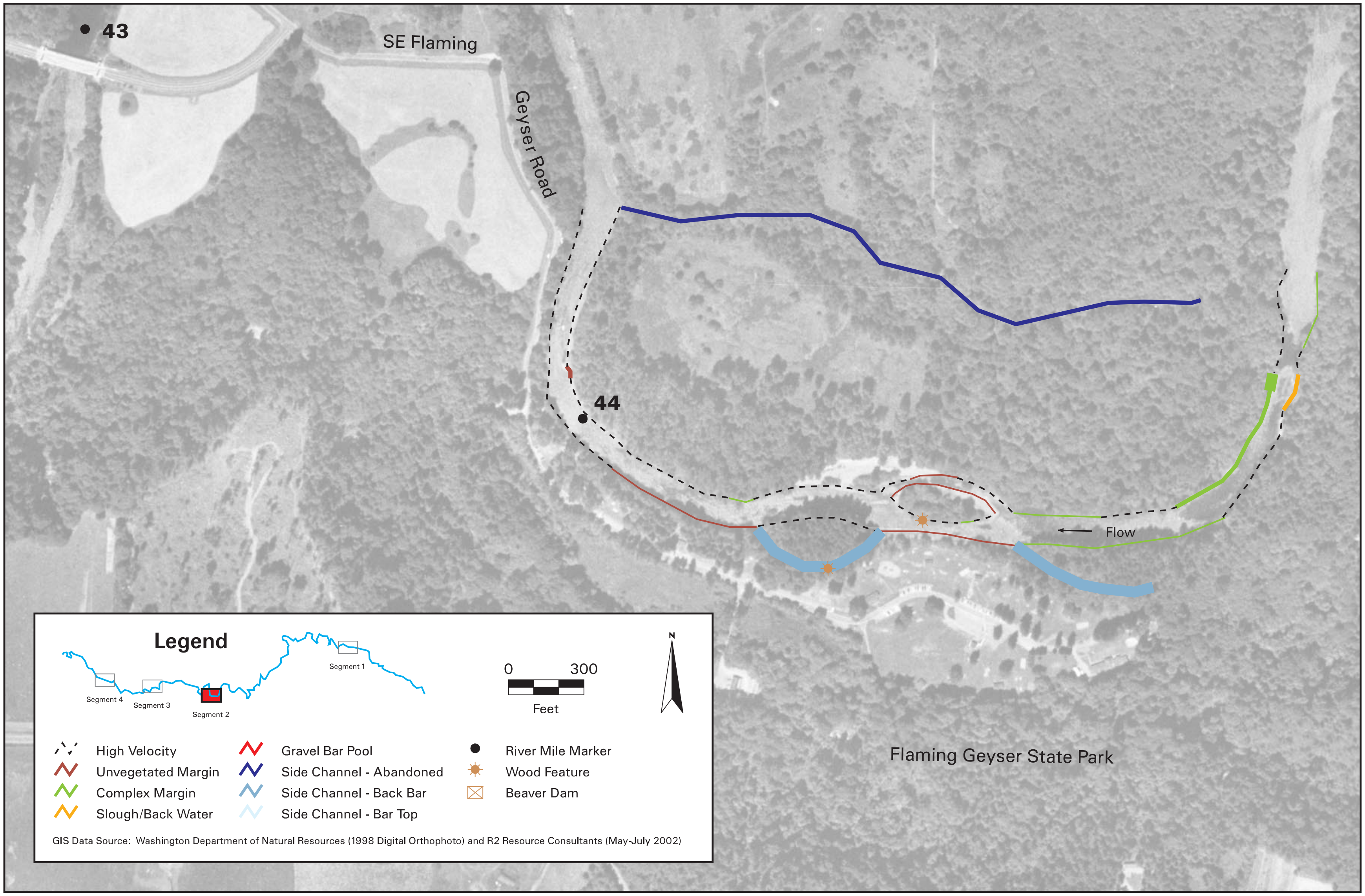

Figure A−6. Lateral habitat study segment 2 under low flow regime (800 cfs), middle Green River, Washington, 2002.

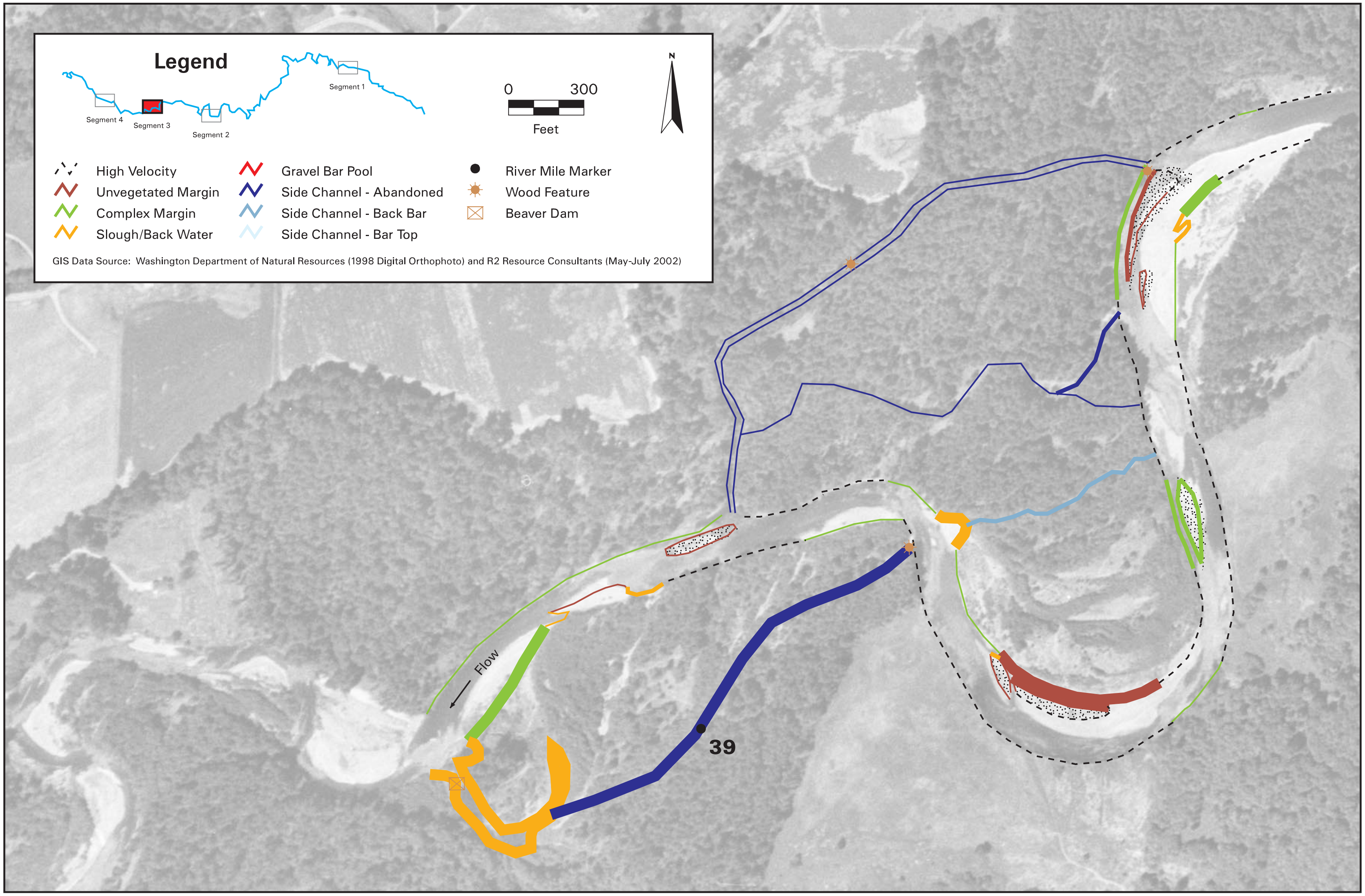

Figure A−7. Lateral habitat study segment 3 under high flow regime (2,100 cfs), middle Green River, Washington, 2002.

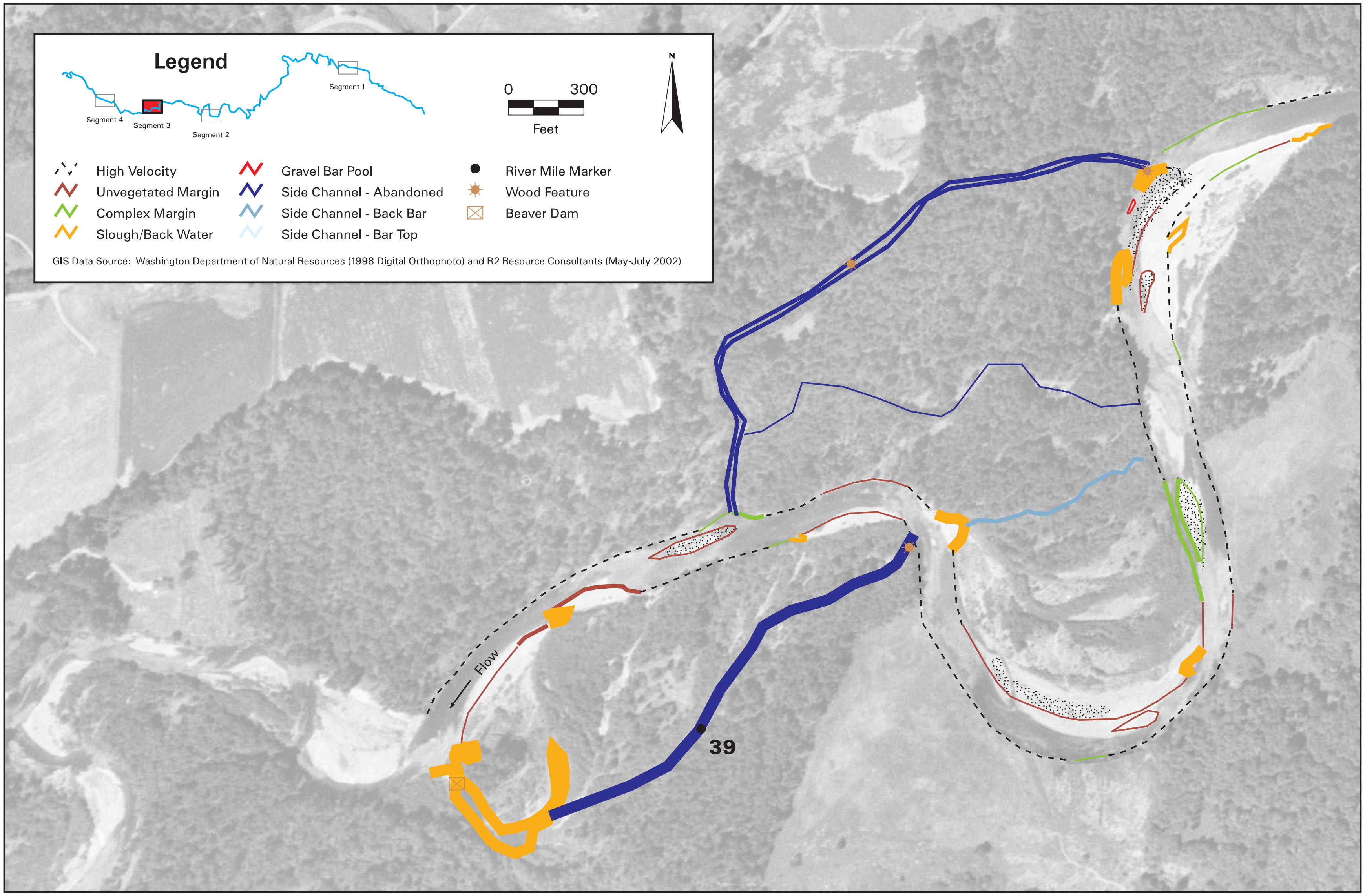

Figure A−8. Lateral habitat study segment 3 under moderate flow regime (1,200 cfs), middle Green River, Washington, 2002.

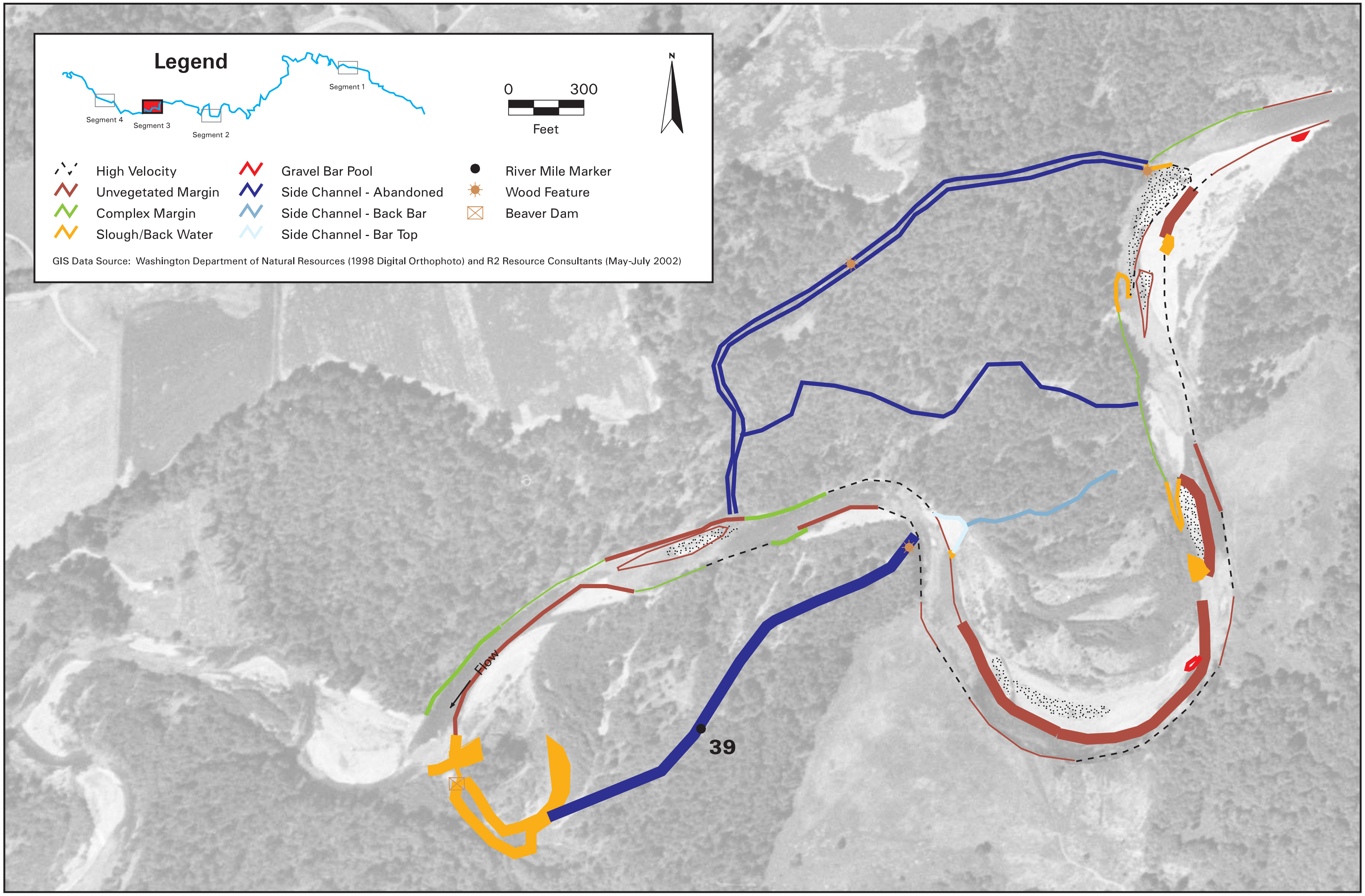

Figure A−9. Lateral habitat study segment 3 under low flow regime (800 cfs), middle Green River, Washington, 2002.

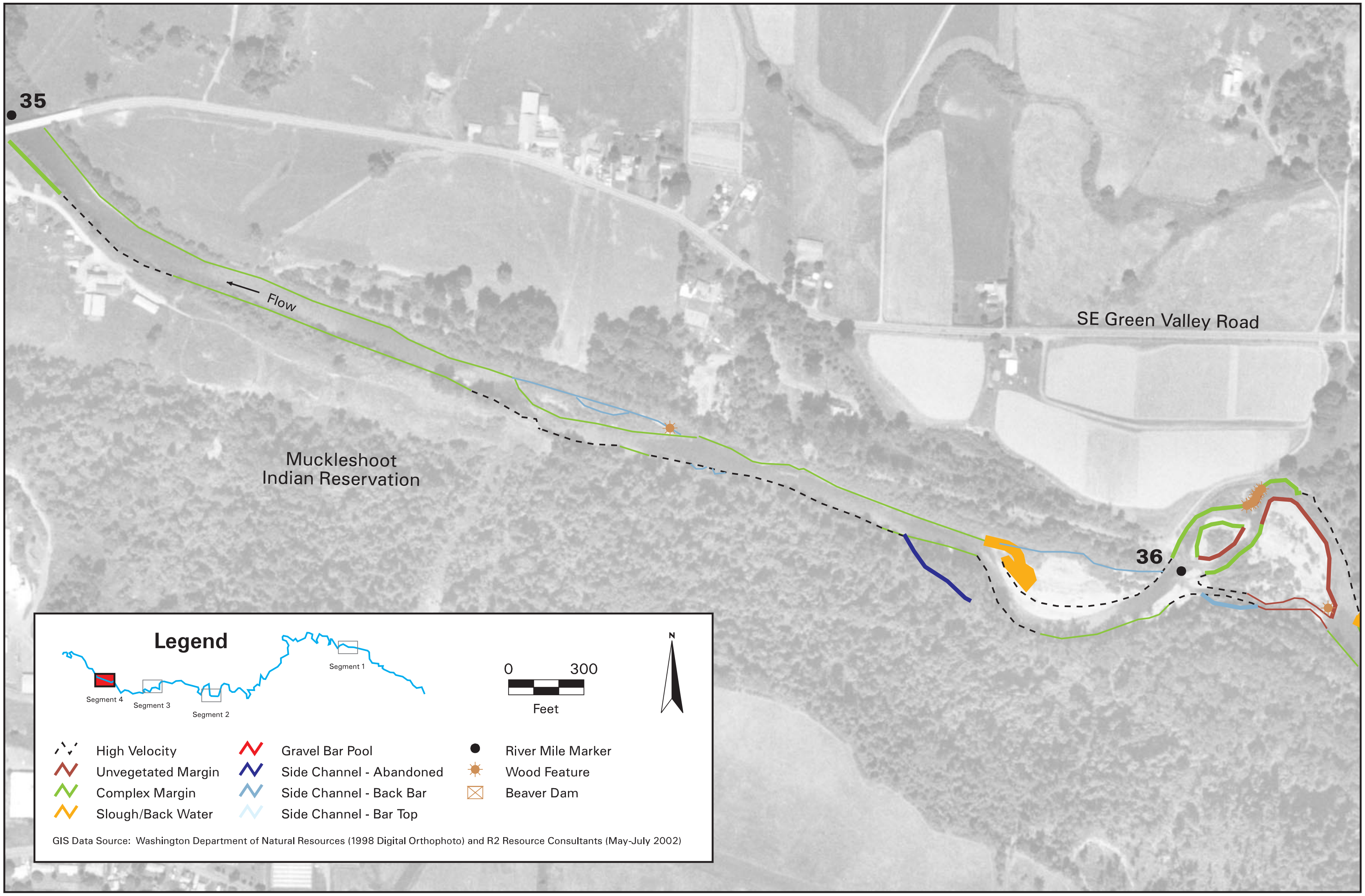

Figure A−10. Lateral habitat study segment 4 under high flow regime (2,100 cfs), middle Green River, Washington, 2002.

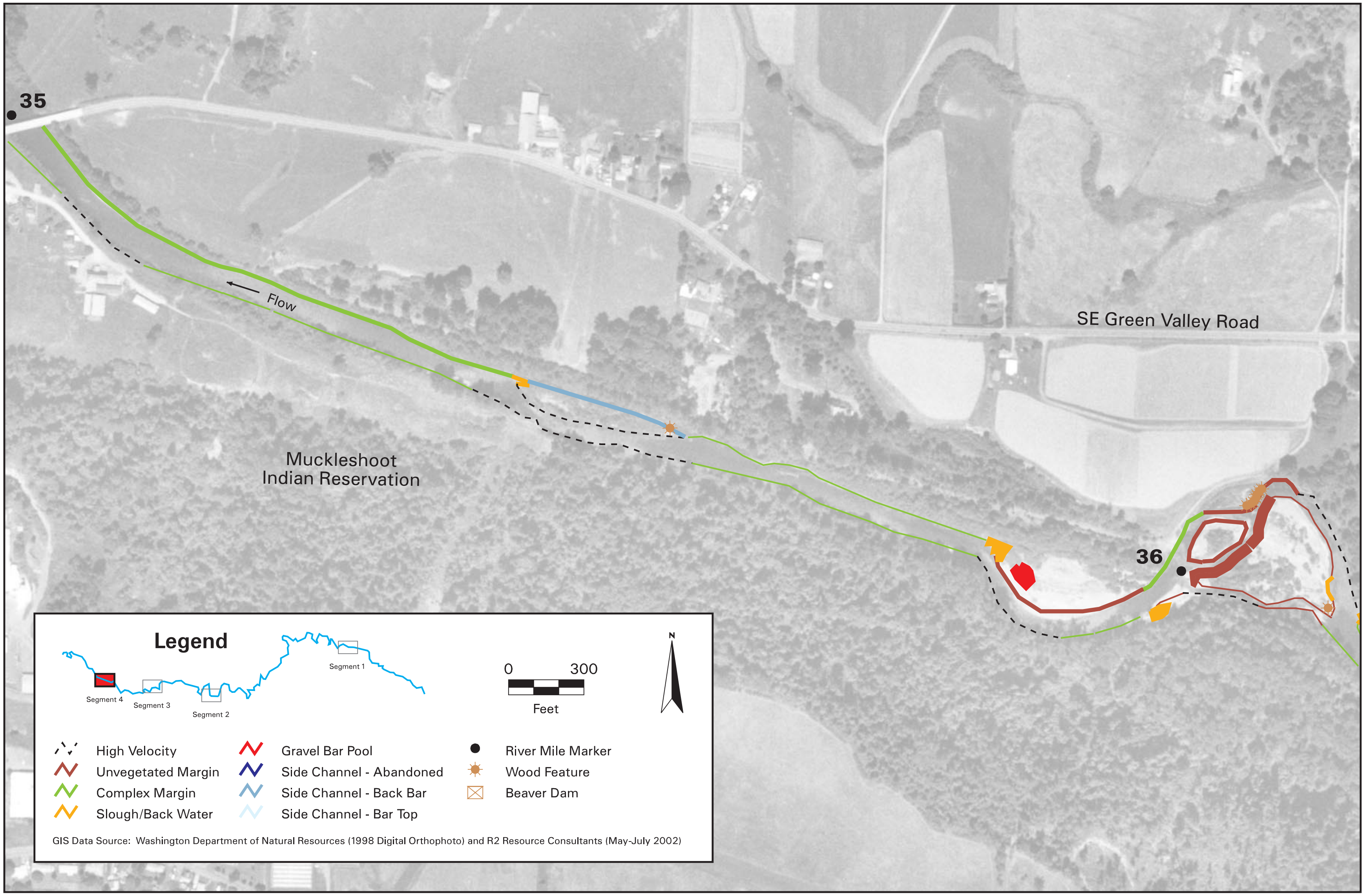

Figure A−11. Lateral habitat study segment 4 under moderate flow regime (1,200 cfs), middle Green River, Washington, 2002.

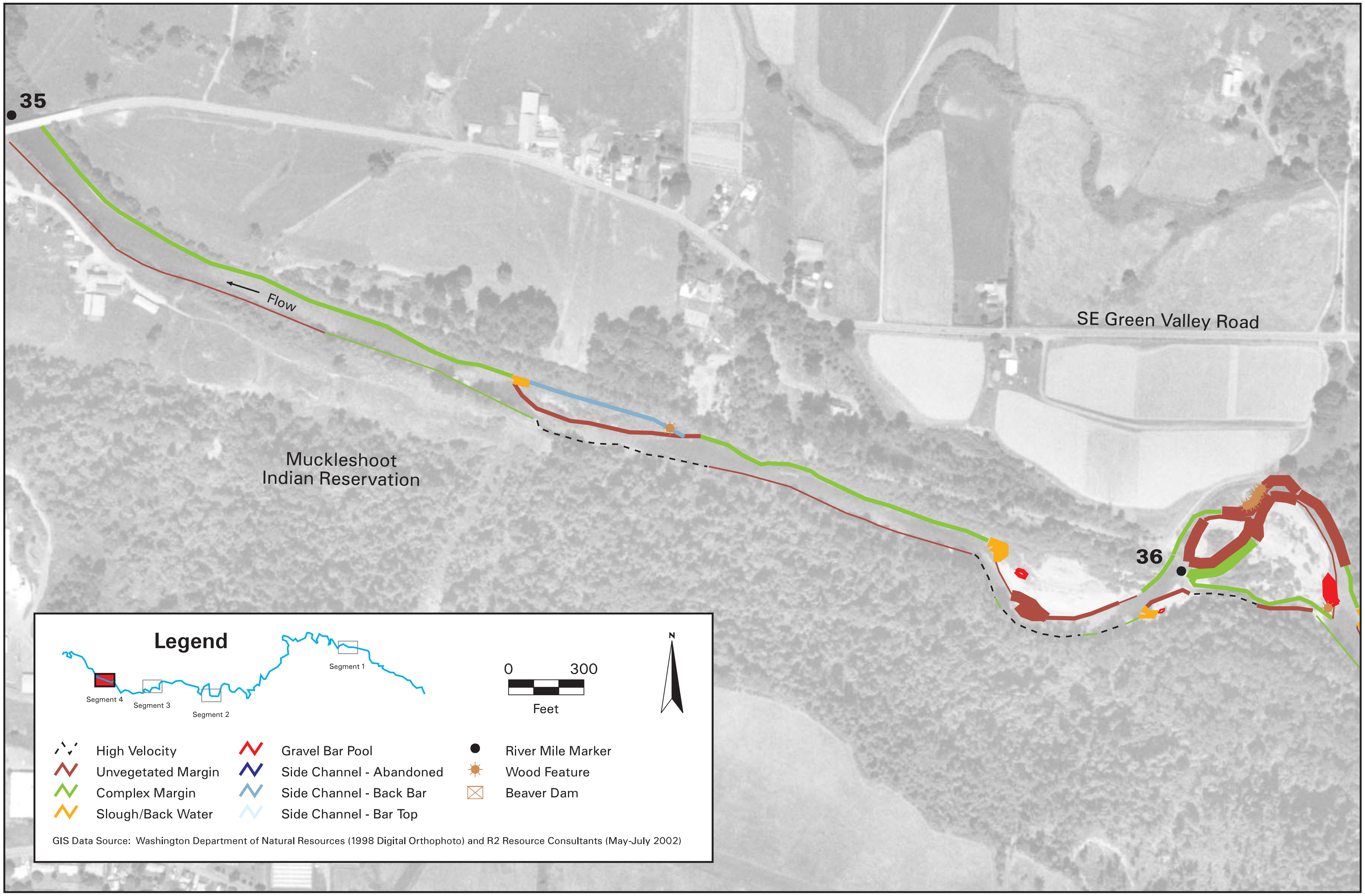

Figure A−12. Lateral habitat study segment 4 under low flow regime (800 cfs), middle Green River, Washington, 2002.

Table A-1. Summary of study segment 1 mainstem margin habitat metrics by width class under three discharge levels, middle Green River, Washington, 2002.

Habitat Type	Total Length (ft)	1-5 ft	5-15 ft	>15 ft
		High Flow (2,100 cfs)		
High Velocity (<1 ft of <1 fps)	9,789			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	1,258	1,258	0	0
Natural - Low Gradient	3,001	2,884	117	0
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	184	184	0	0
Steep, eroding	0	0	0	0
Low Gradient	0	0	0	0
Slough/Backwater				
Vegetated	298	0	298	0
Bare	149	0	0	149
Gravel bar pool	0	0	0	0
		Moderate Flow (1,200 cfs)		
High Velocity (<1 ft of <1 fps)	9,579			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	1,743	1,238	505	0
Natural - Low Gradient	3,117	3,117	0	0
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	198	198	0	0
Steep, eroding	0	0	0	0
Low Gradient	0	0	0	0
Slough/Backwater				
Vegetated	75	0	0	75
Bare	227	0	0	227
Gravel bar pool	0	0	0	0
		Low Flow (800 cfs)		
High Velocity (<1 ft of <1 fps)	0			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	0	0	0	0
Natural - Low Gradient	3,221	728	2,493	0

Habitat Type	Total Length (ft)	1-5 ft	5-15 ft	>15 ft
Unvegetated				
Rip Rap	0			
Bedrock	209	0	0	209
Steep, eroding	1,522	1,522	0	0
Low Gradient	9,761	592	9,169	0
Slough/Backwater				
Vegetated	80	0	80	0
Bare	194	0	0	194
Gravel bar pool	0	0	0	0

Table A-2. Summary of study segment 2 mainstem margin habitat metrics by width class under three discharge levels, middle Green River, Washington, 2002.

Habitat Type	Total Length (ft)	1-5 ft	5-15 ft	>15 ft
		High Flow (2,100 cfs)		
High Velocity (<1 ft of <1 fps)	7,768			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	489	489	0	0
Natural - Low Gradient	1,126	883	243	0
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	0	0	0	0
Low Gradient	172	172	0	0
Slough/Backwater				
Vegetated	330	0	330	0
Bare	123	0	123	0
Gravel bar pool	0	0	0	0
		Moderate Flow (1,200 cfs)		
High Velocity (<1 ft of <1 fps)	5,958			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	2,238	2,238	0	0
Natural - Low Gradient	312	157	155	0
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	536	536	0	0
Low Gradient	110	110	0	0
Slough/Backwater				
Vegetated	273	273	0	0
Bare	0	0	0	0
Gravel bar pool	0	0	0	0
		Low Flow (800 cfs)		
High Velocity (<1 ft of <1 fps)	5,781			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	1,325	1,325	0	0
Natural - Low Gradient	1,043	349	627	67

Habitat Type	Total Length (ft)	1-5 ft	5-15 ft	>15 ft
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	0	0	0	0
Low Gradient	1,885	1,834	51	0
Slough/Backwater				
Vegetated	154	0	154	0
Bare	0	0	0	0
Gravel bar pool	0	0	0	0

Table A-3. Summary of study segment 3 mainstem margin habitat metrics by width class under three discharge levels, middle Green River, Washington, 2002.

Habitat Type	**Total Length (ft)**	**1-5 ft**	**5-15 ft**	**>15 ft**
		High Flow (2,100 cfs)		
High Velocity (<1 ft of <1 fps)	6,737			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	3,109	2,554	555	0
Natural - Low Gradient	2,613	806	1,060	747
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	191	191	0	0
Low Gradient	3,693	2,118	465	1,110
Slough/Backwater				
Vegetated	2,843	198	411	2,234
Bare	39	0	39	0
Gravel bar pool	0	0	0	0
		Moderate Flow (1,200 cfs)		
High Velocity (<1 ft of <1 fps)	7,434			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	666	666	0	0
Natural - Low Gradient	1,668	681	987	0
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	496	496	0	0
Low Gradient	4,965	4,419	546	0
Slough/Backwater				
Vegetated	582	0	426	156
Bare	3,196	0	94	3,102
Gravel bar pool	133	133	0	0
		Low Flow (800 cfs)		
High Velocity (<1 ft of <1 fps)	3,812			
Complex				
Rip Rap	0	0	0	0
Natural-Steep	2,827	2,026	801	0
Natural - Low Gradient	0	0	0	0
Unvegetated				

Habitat Type	Total Length (ft)	1-5 ft	5-15 ft	>15 ft
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	2,027	1,742	285	0
Low Gradient	6,412	2,251	1,939	2,222
Slough/Backwater				
Vegetated	2,678	0	778	1,900
Bare	620	0	167	453
Gravel bar pool	452	0	452	0

Table A-4. Summary of study segment 4 mainstem margin habitat metrics by width class under three discharge levels, middle Green River, Washington, 2002.

Habitat Type	Total Length (ft)	1-5 ft	5-15 ft	>15 ft
		High Flow (2,100 cfs)		
High Velocity (<1 ft of <1 fps)	5,053			
Complex				
Rip Rap	2,466	2,174	292	0
Natural-Steep	5,346	4,157	1,189	0
Natural - Low Gradient	542	542	0	0
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	106	0	106	0
Low Gradient	1,645	694	951	0
Slough/Backwater				
Vegetated	920	125	0	795
Bare	0	0	0	0
Gravel bar pool	0	0	0	0
		Moderate Flow (1,200 cfs)		
High Velocity (<1 ft of <1 fps)	4,201			
Complex				
Rip Rap	298	298	0	0
Natural-Steep	5,004	2,438	2,566	0
Natural - Low Gradient	2,134	2,134	0	0
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	1,009	0	723	286
Low Gradient	2,838	1,527	1,094	217
Slough/Backwater				
Vegetated	534	0	258	276
Bare	107	0	107	0
Gravel bar pool	174	0	0	174
		Low Flow (800 cfs)		
High Velocity (<1 ft of <1 fps)	1,600			
Complex				
Rip Rap	3,220	0	3,220	0
Natural-Steep	2,680	1,328	832	520
Natural - Low Gradient	620	0	620	0

Habitat Type	**Total Length (ft)**	**1-5 ft**	**5-15 ft**	**>15 ft**
Unvegetated				
Rip Rap	0	0	0	0
Bedrock	0	0	0	0
Steep, eroding	2,537	891	801	845
Low Gradient	4,329	2,641	900	788
Slough/Backwater				
Vegetated	226	0	226	0
Bare	286	0	138	148
Gravel bar pool	369	61	102	206

Table A-5. Summary of study segment 1 off-channel habitat under three discharge levels, middle Green River, Washington, 2002.

Unit ID	Side Channel Type	Length (ft)	Inlet Depth (ft)	Inlet Discharge (cfs)	Outlet Discharge (cfs)	Mean Velocity (fps)	Inflow temp (ºC)	Outflow temp (ºC)	Side Channel Width (ft)	Margin Width class	Water Source	Comments
						High Flow (2,100 cfs)						
RB59.2	Backbar	280	0.20	-	-		8.0	8.0	10	2	Mainstem	Fry are using; Substrate boulder
RB58.9	Backbar	548	1.1	-	-	>1	8.0	8.0	15	1	Mainstem	Swift velocity, minimal margin habitat
RB58.6	Abandoned	137	>3.0	-	-	>1	-	-	20	0	Mainstem	Swift velocity, minimal margin habitat
LB58.9	Bartop	425	-	-	-	<0.5	-	-	10	2	GW (from wetland)	Signani outlet; fry present
LB58.8a	Abandoned	121	0.8	-	-	>1	-	-	15	1	Mainstem	Complex consists of SC 2,3,4
LB58.8b	Backbar	419	1.5	-	-	>1	-	-	40	1	Mainstem	complex 600 ft long
LB58.8c	Abandoned	94	1.7	-	-	>1	-	-	30	1	Mainstem	
LB58.8d	Abandoned	68	1.1	-	-	>1	-	-	30	1	Mainstem	
Total Area	41,477 sq ft											
						Moderate Flow (1,200 cfs)						
LB58.9	Abandoned	407	-	-	3	<0.5	-	10.0	5	5-15 ft	Wetland	Signani outlet
RB58.6	Backbar	550	0.8	-	-	>1	12.0	11.0	20	1-5 ft	Mainstem	
LB58.8b	Backbar	432	1.5	-	-	>1	-	-	30	1-5 ft	Mainstem	
LB58.8a	Bartop	173	0.8	-	-	<0.5	-	-	12	5-15 ft	Mainstem	
LB58.8c	Bartop	67	0.6	-	-	0.5-1	-	-	25	5-15 ft	Mainstem	
RB58.6	Bartop	144	>2.0	-	-	>1	-	-	20	<1 ft	Mainstem	
Total Area	32,626 sq ft											

Unit ID	Side Channel Type	Length (ft)	Inlet Depth (ft)	Inlet Discharge (cfs)	Outlet Discharge (cfs)	Mean Velocity (fps)	Inflow temp (ºC)	Outflow temp (ºC)	Side Channel Width (ft)	Margin Width class	Water Source	Comments
						Low Flow (800 cfs)						
LB58.9	Abandoned	410	-	-	-	<0.5	9.5	10.0	4	1-5 ft	Wetland/GW	Sig slough out; main temp 13.5
LB58.8a	Bartop	176	0.20	-	-	<0.5	13.0	13.0	10	5-15 ft	Mainstem	
LB58.8c	Bartop	74	0.6	-	-	>1	-		10	1-5 ft	Mainstem	
LB58.8b	Backbar	443	0.8	-	-	>1	-		20	5-15 ft	Mainstem	
RB58.9	Backbar	568	0.20	-	-	<0.5	14.5	14.5	18	>15 ft	Mainstem	
RB58.6	Bartop	124	>1	-	-	>1	-		20	1-5 ft	Mainstem	Some margin habitat
Total Area	25,696 sq ft											

Table A-6. Summary of study segment 2 off-channel habitat under three discharge levels, middle Green River, Washington, 2002.

Unit ID	Side Channel Type	Length (ft)	Inlet Depth (ft)	Inlet Discharge (cfs)	Outlet Discharge (cfs)	Mean Velocity (fps)	Inflow temp (ºC)	Outflow temp (ºC)	Side Channel Width (ft)	Margin Width class	Water Source	Comments
High Flow (2,100 cfs)												
RB44.6	Abandoned	2,799	0.7	3	4.5	0.5	9.7	10.8	15	1-5 ft	Mainstem/GW	Fry@inlet near LWD and thru SC
LB44.3a	Backbar	280	-0.05	-	-	-	-	-	5	1-5 ft	Trib	Fed by Christy; flow out inlet 197 ft
LB44.3b	Backbar	701	dry	-	-	-	-	-	20	5-15 ft	Trib	Fed by Christy; 1,083 ft long
LB44.2	Backbar	571	1.4	-	-	>1	9.5	9.5	30	1-5 ft	Mainstem	
Total Area	74,534 sq ft											
Moderate Flow (1,200 cfs)												
LB44.3a	Backbar	288	0	dry	-	<1	-	-	5	1-5 ft	Trib	Christy flows out both ends
LB44.3b	Backbar	679	0	dry	-	<1	-	-	20	>15 ft	Trib	Main Christy outflow
LB44.2	Backbar	587	1.2	-	-	>1	-	-	27	1-5 ft	Mainstem	
RB44.25a	Bartop	62	0.1	-	-	<0.5	-	-	3	1-5 ft	Mainstem	
RB44.25b	Bartop	121	0.1	-	-	<0.5	-	-	6	5-15 ft	Mainstem	Length=180 ft
RB44.6	Abandoned	1,737	dry	dry	-	<0.5	-	11.0	20	>15 ft	GW/Wetland	No inflow; 2,480 ft long
Total Area	66,532 sq ft											
Low flow (800 cfs)												
RBSC1	Abandoned	2,458	0.0	dry	0.2	<1	14.0	13.5	5	5-15 ft	GW/Wetland	Flow starts 350 ft DS of inlet
LBSC1	Backbar	596	dry	-	-	<0.5	-	-	20	>15 ft	Trib	Disconnect @U/S
LBSC2	Backbar	599	-	-	-	-	-	-	20	>15 ft	Mainstem	
Total Area	36,190 sq ft											

Table A-7. Summary of study segment 3 off-channel habitat under three discharge levels, middle Green River, Washington, 2002.

Unit ID	Side Channel Type	Length (ft)	Inlet Depth (ft)	Inlet Discharge (cfs)	Outlet Discharge (cfs)	Mean Velocity (fps)	Inflow temp (ºC)	Outflow temp (ºC)	Side Channel Width (ft)	Margin Width class	Water Source	Comments
High Flow (2,100 cfs)												
RB39.8	Abandoned	2,627	3.0+	-	>500	>1.0	8.0	8.0	72	1	Mainstem	MOAS; almost 50% of main flow; 72 ft wide
RB39.5	Abandoned	1,875	1.4	-	>50	>1			18	1	Mainstem	
RB39.6	Abandoned	428	0.3	-	-	<0.5	9.0		5	2	Mainstem	429 ft long; many fry
RB39.45	Bartop	849	0.2	-	1.3	<0.5	9.0	8.0	8	2	Mainstem/ GW	946 ft long
LB39.3	Abandoned/ Wallbase	1,837	ND	-	-				20	3	Mainstem	Inlet below log/length from photo
Total Area	268,537 sq ft											
Moderate Flow (1,200 cfs)												
RB39.8	Abandoned	2,629	>2.0	-	-	-	-	-	60	5-15 ft	Mainstem	MOAS; Swift throughout
RB39.5	Abandoned	1,860	-	20	-	>1	-	-	16	1-5 ft	Surface	
LB39.3	Abandoned/ wallbase	1,913	-	-	-	-	-	-	20	>15 ft	Surface	same as Lower O'Grady
RB39.45	Backbar	804	dry	dry	3.5	<0.5	-	10.5	10	5-15 ft	GW	Groundwater fed; no inflow; fry
Total Area	233,811 sq ft											
Low Flow (800 cfs)												
RBSC1	Abandoned	2,593	-	-	-	>1	-	-	60	5-15 ft	Mainstem	MOAS still swift

Unit ID	Side Channel Type	Length (ft)	Inlet Depth (ft)	Inlet Discharge (cfs)	Outlet Discharge (cfs)	Mean Velocity (fps)	Inflow temp (ºC)	Outflow temp (ºC)	Side Channel Width (ft)	Margin Width class	Water Source	Comments
RBSC3	Abandoned	1,870	0.5	8.2	-	<1	-	-	13	5-15 ft	Mainstem	Flows into Moas
RBSC7	Backbar	267	0.02	-	-	-	-	-	10	5-15 ft	Mainstem	57 ft long
LBSC1	Abandoned/ Wallbase	1,906	-	-	-	-	-	-	20	>15 ft	Mainstem/ GW	Inlet obscured by debris jam
RBSC6	Bartop	677	-0.09	0.0	2.9	<1	-	-	8	5-15 ft	GW	Lower Metzler site @DS
Total Area	226,059 sq ft											

Table A-8. Summary of study segment 4 off-channel habitat under three discharge levels, middle Green River, Washington, 2002.

Unit ID	Side Channel Type	Length (ft)	Inlet Depth (ft)	Inlet Discharge (cfs)	Outlet Discharge (cfs)	Mean Velocity (fps)	Inflow temp (ºC)	Outflow temp (ºC)	Side Channel Width (ft)	Margin Width class	Water Source	Comments
						High Flow (2,100 cfs)						
RB36.0	Backbar	674	0.7	-	-	<0.5	11.0	13.0	4	1-5 ft	GW/Mainstem	Connected; low inflow; GW @50 ft; fry
RB35.5	Backbar	713	1.9	-	-	>1	11.0	10.0	25	1-5 ft	Mainstem	Swift; jam at US end
RB35.5a	Backbar	231	0.2	-	-	>1	11.0	11.0	3	1-5 ft	Mainstem	SC off main flow; fry; l=183 ft
LB36.1	Backbar	237	0.14	-	-	<0.5	10.0	10.0	8	5-15 ft	Mainstem	Length=255 ft
LB35.9	Abandoned	380	0.7	-	-	<0.5	-	11.5	12	5-15 ft	GW	GW-fed; no inflow; fry 380 ft
LB35.6	Backbar	68	0.5	-	-	<0.5	-	-	4	1-5 ft	Mainstem	40 ft long; surface flow
LB35.55	Backbar	75	0.7	-	-	<0.5	-	-	5	1-5 ft	Mainstem	around LWD, grass; fry present
Total Area	28,322 sq ft											
						Moderate Flow (1,2000 cfs)						
RB35.5	Backbar	664	1.1	-	-	>1	-	-	15	5-15 ft	Mainstem	Flow all in single channel
Total Area	9,953 sq ft											
						Low Flow (800 cfs)						
RB35.5	Backbar	652	0.45	-	-	-	-	-	5	5	Mainstem	
Total Area	3,260 sq ft											